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THE DRY-MATTER CONTENT OF CERTAIN GRASS AND CLOVER SPECIES

W. E. J. MILTON

(*Welsh Plant Breeding Station, Aberystwyth*)

INVESTIGATIONS conducted at the Welsh Plant Breeding Station on the dry-matter content of herbage plants have shown that variation exists in this respect among species, but that certain factors have an influence upon dry matter apart from species and strain. Thus Stapledon [1], working on grasses during the seasons 1921–3, and Williams [2] on red clovers, found that whilst differences in the percentage of dry matter occurred among the individual species and strains, the precise values were largely influenced by total yield, by the number of cuts taken, and by the meteorological conditions obtaining from the commencement of the growing season.

Sheehy [3, 4] has conducted experiments which indicate that the dry-matter content of pastures is of considerable importance in determining their stock-carrying and fattening capacities. He has shown that differences in the percentage dry matter of the grass, clover, and miscellaneous herb groups are so marked that the value of a pasture is to a large extent determined by the relative proportions of these three groups.

The experiment reported upon in the present paper comprises an investigation supplementary to one on dry-matter content conducted by the writer [5] in 1933.

The Experiment

In the experiment species and strains of grass and strains of red clover were sown in 20 ft. drills, on which a series of pasture-, hay-, and aftermath-cuts were made for percentage dry-matter determinations. For this purpose air-tight 3-litre bottles of known weight were used on the field. The net weight of fresh herbage was obtained by difference, and later the herbage was dried in an oven.

Two pasture-cuts were taken in the autumn of the seeding year (1933) and five more during the following year. The time of cutting was determined by the stage of growth. An early hay-cut was taken from a separate portion of each drill when the herbage was in the heading stage.

Results

The data for the three modes of cutting are given in Table 1. Considering the pasture-cuts first, there are distinct differences in the percentage of dry matter among the species.

Fine-leaved fescue, timothy, and meadow foxtail have given the highest percentages, Italian rye-grass the lowest. It will be observed that red clover is among the lowest, but that it is equal to perennial rye-grass. The data on the grasses are in agreement with the previous investigation by Stapledon [1].

TABLE 1. *Percentage of Dry Matter in Grass Species and Red Clover cut as Pasture, Hay, and Aftermath*

Species	*Number of strains averaged*	*Average of 7 pasture cuts*	*Early hay*	*Aftermath*
Perennial rye-grass	19	23·2	23·9	34·2
Italian rye-grass	3	21·3	23·3	32·0
Cocksfoot	27	23·9	25·5	30·3
Timothy	14	28·4	29·2	29·6
Meadow fescue	7	26·9	25·7	32·9
Tall fescue	3	24·3	24·0	33·3
Crested dogstail	3	25·3	28·0	32·0
Meadow foxtail	5	27·6	28·2	33·0
Fine-leaved fescue	8	28·9	27·7	30·2
Bent (*Agrostis* spp.)	2	26·5	23·0	32·0
Sweet vernal	2	26·0	30·5	28·5
Bromus arvensis	1	27·0	28·0	37·0
Red clover	6	23·2	23·5	24·9

Considering next the data for hay and aftermath, the position of the species in respect of one another is the same as in the pasture-cuts for the majority of the species, exceptions being that cocksfoot, crested dogstail, and sweet vernal have risen in relation to the others, whilst fine-leaved fescue and bent have dropped. The aftermath figures show that perennial and Italian rye-grasses and tall fescue have given higher percentages in relation to the other species than they did as pasture or as hay, but that the reverse is the case with timothy and sweet vernal. Red clover again gave one of the lowest percentages of dry matter.

The most marked feature of the table is that the figures for the hay-cut are on the same level as those for pasture, and that the figures for the aftermath are the highest of all. This aspect of the results will be dealt with later in the discussion.

In Table 2 particulars are given of the percentage dry-matter of the species for the seven pasture-cuts.

The first cut on September 22, 1933, represents growth from the time of sowing on May 5, and the cut on May 7, 1934, represents the accumulated growth throughout the spring. It will be observed that every species shows the same trend, namely, a drop from the relatively high percentage figures of the autumn cuts to those for May 7, and to the still lower figures for May 29: then a sharp rise to those for July 9, succeeded by a fall to August 14; and then, in the majority of cases, a rise to the cut on October 16. It is significant that, without exception, the species have given this seasonal fluctuation in their percentage dry matter; and that the herbage of most of the species, on November 18, consisting entirely of autumn growth, contained more dry matter than the herbage on July 9.

Discussion

A comparison of the data for pasture with those obtained by the writer [5] from grazed plots illustrates the effect of cutting *versus* grazing

TABLE 2. *Percentage of Dry Matter in the Species at each Pasture-cut*

Species	*Date of cut*						
	Sept. 22	*Nov. 18*	*May 7*	*May 29*	*July 9*	*Aug. 14*	*Oct. 16*
Perennial rye-grass	27·0	27·2	21·7	19·4	29·7	18·4	24·7
Italian rye-grass	23·0	18·5	17·7	18·3	28·3	20·0	21·0
Cocksfoot	29·2	28·2	20·8	17·2	26·5	20·1	27·2
Timothy	33·9	33·9	29·0	19·4	32·3	21·7	29·0
Meadow fescue	35·0	29·2	25·1	16·9	28·0	25·4	26·3
Tall fescue	24·6	30·0	22·6	20·3	24·3	22·3	25·0
Crested dogstail	26·0	34·0	23·0	16·3	33·0	25·6	22·0
Meadow foxtail	33·8	32·0	24·6	16·6	31·2	26·0	32·7
Fine-leaved fescue	*	*	33·7	21·3	32·2	26·9	29·4
Bent (*Agrostis* spp.)	*	*	28·0	21·5	27·5	25·0	30·0
Sweet vernal	30·0	38·0	24·5	17·0	35·0	25·0	30·0
Bromus arvensis	27·0	43·0	13·0	11·0	34·0	33·0	27·0
Red clover	26·3	27·5	19·7	16·5	24·8	23·6	*

* Not sufficient material for analysis.

conditions upon the percentage dry-matter content of herbage. In the earlier work samples were taken at several dates in 1933 from plots of pure species which were grazed at three-weekly intervals. The percentage dry-matter of these samples was as follows:

	May 19	*June 15*	*July 11*
Timothy	15·4	23·8	16·6
Bent (*Agrostis* spp.)	23·6	37·8	24·7
Yorkshire fog	14·8	25·1	18·0
Cocksfoot	18·0	25·8	20·1
Meadow fescue	17·0	26·3	21·4
Tall fescue	19·4	29·4	20·7
Fine-leaved red fescue	21·6	28·8	24·4
Perennial rye-grass	17·5	27·3	19·5
Italian rye-grass	14·0	25·6	16·4
Montgomery red clover	17·0	25·6	18·3
Wild white clover	15·2	20·3	16·0

It will be observed that in these data timothy gave figures which were among the lowest for the grasses, whereas under the cutting system it was one of the highest. Under grazing conditions, on the other hand, bent gave significantly higher figures for dry matter than any of the other grasses, but it occupied only an intermediate position in the range of species under the condition of pasture-cuts.

The reason for these differences is that in the case of timothy it was observed that the sheep grazed this species to such a close degree that, although not sampled for dry matter until three weeks' rest had elapsed, the herbage recommenced growth from the very base and was wholly of an immature and succulent nature and consequently of a low dry-matter content.

With bent the opposite was the case, for being of relatively low palatability the herbage sampled always contained a certain amount of mature growth which would have been left ungrazed at the previous date, notwithstanding the fact that any ungrazed herbage was scythed off immediately after each grazing. It was noticed that the scythe never cut a poorly grazed plot as closely as the sheep grazed a very palatable plot.

As a matter of fact, these data from grazed plots give a more accurate picture of the dry-matter content of pastures than the data from the series of pasture-cuts. In farm practice, moreover, where pastures are often under a system of continuous grazing, the differences in the percentage dry-matter content of the most palatable grasses and the least palatable grasses would be still more marked than in the foregoing examination, on account of the animals grazing the former rigorously and to a great extent neglecting the latter.

It will be noted that the dry-matter content of the red clover in the grazed plots gave figures as high as some of the grasses, but that wild white clover gave figures which were lower than those for red clover at each date of sampling.

An examination of the strains of grasses within a species showed no consistent differences in favour of any particular source of origin. The results obtained for the strains of red clover are in keeping with the evidence reported by Williams [2].

The seasonal fluctuation in percentage dry matter which the species showed in the pasture-cuts coincides with the data of Stapledon [1] in his earlier investigation, where he found that the depressions and peaks occur around the dates mentioned, and that the periods of low-percentage dry matter corresponded with greatest total yield. Williams [2] found this negative correlation between percentage dry matter and total yield to be very marked in red clover.

When commenting on the particulars given in Table 1, attention was drawn to the relationship of the figures for pasture, hay, and aftermath. The fact that the percentage dry matter is low in herbage during the end of May and early June accounts for the hay-crop cut in the heading stage on June 12 giving such low figures compared with those for pasture and aftermath. In this connexion Sutton and Voelcker [6] found that hay cut at the heading stage from a permanent sward gave 24·8 per cent. of dry matter, a figure corresponding to that for the species in the hay-cut of the present trial, whereas hay cut at or after the flowering stage gave 32·5 per cent. of dry matter. The high figures for the dry-matter content of the species in the aftermath which was cut on August 30 are accounted for by the herbage of this cut having been an accumulation of the summer growth, the aftermath having been taken after an early hay-cut. Stapledon [1] has shown that length of growing-period affects dry-matter content; moreover, Fagan and Watkin [7] working on the oat plant found that the percentage of dry matter increased with maturity.

Sheehy [3] found as much as 25 per cent. more dry matter in the herbage of one pasture than in that of another, but as the percentage of dry matter in the grass portion of the poorer pasture was similar to that

for the total herbage of the better pasture, which was predominantly grass, he attributes the difference to the relatively high proportion of miscellaneous herbs present in the poorer pasture. It is, however, interesting to observe that in view of the data on grass species referred to and reported upon in the present paper, the percentage of dry matter will differ from pasture to pasture both in accordance with the grass species that dominate the sward and with the intensity of the grazing. Thus a poor-class pasture containing bent (*Agrostis* spp.) as its chief grass will contain a higher percentage of dry matter in the grass portion of its herbage than a pasture containing perennial rye-grass as its dominant grass.

Crampton [8] points out that because grasses have a greater dry-matter content than clovers it does not follow that they will yield more net energy to animals, for in regard to feed the fibre-content has to be considered. He describes the undesirable effects of fibre in the feed and cites figures to show the lower percentage of fibre in white clover compared with that in certain grasses, thus concluding that difference in fibre-content may tend to balance the lower dry-matter content of clovers and higher dry matter of grasses. In view of the data here under discussion it would seem that this comparison would apply chiefly to wild white clover in permanent pastures and only to a lesser degree to red clover in temporary swards.

Summary

An investigation has been made into the percentage of dry matter of grass species and red clover when cut as pasture, hay, and aftermath.

Differences among the species were found to occur under each system of cutting.

The pasture-cuts showed marked seasonal variation, the lowest percentage dry matter occurring during late May and early June, when maximum growth is being made. The pasture-cuts in July, October, and November, gave the highest figures of the series for dry matter.

A comparison of the data with those of previous work showed that the dry-matter content of a species when grown under grazing conditions is affected by its palatability.

The species when cut for hay in the heading stage gave figures for percentage dry matter similar to the average of the pasture-cuts. The subsequent aftermath, consisting of mature herbage, gave higher dry-matter content than the hay and pasture.

The influence of percentage dry matter of herbage on the value of pastures is discussed.

Acknowledgement

The writer desires to thank Professor R. G. Stapledon for the critical interest he has taken in the investigation.

REFERENCES

1. R. G. Stapledon, Seasonal Productivity of Herbage Plants. Welsh Plant Breeding Station Bulletin Series H. No. 3 (1924), 5–84.

2. R. D. WILLIAMS, The Productivity of Different Strains and Nationalities of Red Clover. Ibid. 131–50.
3. E. J. SHEEHY, The Correlation of Nutritive Values with Dry-Matter Content of Pastures. Sci. Proc. Roy. Dublin Soc., 1927, **18** (N.S.), 389–98.
4. —— Factors which determine the Nutritive Value (Stock-carrying and Fattening-capacity) of Untreated Natural Pastures. Ibid. **20** (N.S.), 325–46.
5. W. E. J. MILTON, The Palatability of the Self-establishing Species contributing to Different Types of Grassland. Empire J. Expt. Agric., 1933, **1**, 347–60.
6. MARTIN J. SUTTON and J. A. VOELCKER, Relative Feeding-value of Grass cut at Different Periods of Growth. J. Bath and West and Southern Counties Soc., 1891–2, Fourth Ser., **2**.
7. T. W. FAGAN and J. E. WATKIN, The Distribution of the Nitrogenous and Mineral Constituents in the Oat Plant at Different Stages of Growth. Welsh J. Agric., 1931, **7**, 229–46.
8. E. W. CRAMPTON, Pasture Studies IV: Nutritive Value of Pasture Herbage: Quality of Protein. Empire J. Expt. Agric., 1934, **2**, 337–48.

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OBSERVATIONS ON COFFEE IN KENYA

INTRODUCTORY *by* A. D. TRENCH, *Senior Coffee Officer, and* V. A. BECKLEY,
Senior Agricultural Chemist, Kenya Department of Agriculture, and

Pt. I, CHLOROSIS AND DIE-BACK IN COFFEE, *by* V. A. BECKLEY

With Plates 13, 14

Introductory

COFFEE, *Coffea arabica*, has been grown in the Highlands of Kenya for a good many years, but it is only during the past seven or eight years that it has been possible for any concerted scientific observations to be made on the real cultural side of coffee-growing. The information accumulated during these years has shown us that coffee is a crop that is capable of adapting itself to widely divergent conditions and behaving differently under each set.

Under a certain concatenation of conditions, active root-growth occurs during the rainy seasons, under another set the roots are most active when the content of soil moisture is not too high, after the rains. Sometimes the cutting of a main lateral root involves the nearly complete loss of the functions of that root; a mass of short hair-roots develops only at the cut end. Elsewhere the effect of cutting a root is ephemeral. Again, in some parts coffee will bear a good crop year after year; in others a good crop is accompanied by very severe die-back and there is no crop the next year.

Such variable behaviour complicates all advisory work. Cultivation methods, cultural practices, and manurial treatments have all to be adjusted in order to meet the reactions of the plant to each set of conditions. It is impossible to generalize beyond simple basal concepts.

These same wide variations in habit observed, have encouraged us to take advantage of the foundation ideal of the *Empire Journal of Experimental Agriculture* and publish the various observations of the officers of the Department of Agriculture, Kenya, concerned in coffee investigational work, in the hope that these may be of help to other workers on coffee, and in the hope that they too will publish their observations to be of assistance to us. It is proposed to publish at intervals a series of papers on all the aspects of the work now in progress on coffee cultural practices.

I. CHLOROSIS AND DIE-BACK IN COFFEE

Chlorosis and die-back are troubles encountered in coffee-cultivation everywhere. In East Africa whole plantations may become chlorotic, showing up as yellow patches in the general landscape, and very often accompanied by severe die-back of branches. Usually it is only trees carrying a crop that suffer chlorosis, but sometimes chlorosis will persist after the crop has been picked, and certain forms may occur whether a crop is being carried or not. The causes of the condition have been a matter of speculation or have been overlooked.

In 1929–30, after a season of long continued heavy rain, chlorosis was almost universal in Kenya. The condition was shown by the writer [1] to be due to a lack of available nitrogen while the crop was developing. Sanders and Wakefield [2, 3, 4] consider that the chlorosis and die-back occurring in the Northern Province, Tanganyika Territory, is due to an inadequate supply of nitrates at the period of maximum demand, and ascribe chlorosis during the rains to waterlogging with possible denitrification. Nutman [5] on the contrary, attributes chlorosis and die-back to a deficiency in the carbohydrate-supply during the period of heavy demand.

Investigations during the past three years have led the writer to the conclusion that in East Africa there are at least two main types of chlorosis and die-back recognizably due to physiological disturbances. One is directly due to an inadequate supply of available nitrogen at the period of greatest demand, and can be alleviated by the application of a readily available nitrogenous fertilizer, provided the soil-moisture conditions are suitable. The other main type is definitely ascribable to a deficiency in the carbohydrate-supply while the crop is developing most rapidly and can only be alleviated by stripping the crop; it is, in fact, a case of sheer overbearing. In each form there are certain symptoms which are readily recognized, and so it is possible to adjust the treatment to the needs of the case. The matter is somewhat complicated by the fact that both forms occur simultaneously.

Two other types of chlorosis, certainly due to physiological disturbances, have been recognized. Although the ultimate causes are not known, the symptoms will be described. It is recognized that both chlorosis and die-back may be caused by insect damage or the effects of disease organisms, but this aspect of the subject is beyond the purview of this paper.

Chlorosis due primarily to nitrogen-deficiency.—This form of chlorosis is the commonest type found in coffee on the eastern side of the Rift Valley and thus has been closely studied for some years. The symptoms of nitrogen-deficiency in the field are easily recognized and have been described [6]. Under extreme lack of nitrogen, such as can be arranged in pot-experiments, trees, as is to be expected, are chlorotic, but under field conditions chlorosis appears only when a crop is carried. Any operation or condition liable to lead to a shortage of available nitrogen, such as long-continued rain or drought, poor or denuded soil improperly managed or grassed, or the ploughing under of a strawy green manure among others, will cause bearing trees to turn yellow and perhaps to suffer die-back.

The first stage in the chlorosis is a paling of the normal dark green colour of the leaves. Any leaves produced at this stage are undersized. The main veins turn yellow and mature leaves are apt to be shed; the yellow colour spreads from the veins until almost the whole blade of the leaf is involved. The tone of the colour is rather a lemon yellow. Nearly mature leaves are shed and the yellow apical leaves together with the growing point die. Usually the apical leaves drop off as they die, and it is the writer's belief that, in die-back due purely to nitrogen-deficiency,

the shedding of the apical leaves is typical, and that where they are retained there is another contributory factor. The death of the growing-point is followed by a progressive dying-back of the branch, which may involve the whole, spoiling the tree. Innumerable cases have been observed where the middle primaries have thus been lost, giving a tree consisting of two tufts, a large bottom tuft and a small upper one, with a length of bare stem between.

The crop suffers severely. Although a large crop of cherry may be ripened, the output of clean coffee will be very low. In one case only 2 per cent. of good coffee in place of the usual 22–5 per cent. was obtained from the cherry picked; most of the cherry was either empty or contained fragmentary beans. Cross-sectioning cherries from trees in a state of die-back forms one of the most valuable means of diagnosis, the sections showing various stages in the formation of empty beans (Fig. 1, Plate 13). Chlorosis usually starts when the bean is passing from the 'water' to the 'milk' stage; thus any changes in the macro-structure of the bean are easily seen. In many cases a small clear green patch will be seen at the basal end of the white endosperm, indicating a mobilization of food stored in the seed; such a patch is visible in the lower bean of Fig. 1*b*. The mobilization and transport of deposited food either to the contiguous bean or to other cherries proceed, in deficiency of nitrogen, until either only a thin cellulosic membrane or a fragment of the bean is left. In the cross-section shown in Fig. 1*e*, one bean has been broken down almost completely; in the longitudinal section, Fig. 1*f*, only a membrane is left of one bean and a small fragment of the other. Since die-back almost always accompanies severe chlorosis, breaking-down of the beans always starts at the distal end of the branch, and, if die-back is not too severe, quite good coffee may be picked from the basal ends of bearing branches.

There is a liability for true breaking-down of the beans to be confused with the collapse of beans due to drought conditions, especially when collapse occurs during the early stages of development. In collapsed beans the whole endosperm shrinks away from the parchment-like endocarp; breaking-down starts from one end of the folded sperm.

The application of a readily available nitrogenous manure not only arrests the breaking-down of the crop but also, if breaking-down has not proceeded too far, food is redeposited. In one case where a whole plantation had become chlorotic an application of a nitrogenous fertilizer was advised. At the time it was found by cutting across cherries, picked at random from a number of trees, that more than one-half of the beans were breaking down. Two months later, although chlorosis was still evident, it was difficult to find any beans breaking down; die-back, too, had been arrested. Next year the trees were healthy and vigorous and carried a good crop. In another case, that of a single tree in the grounds of the laboratory, growing on soil which had suffered erosion, the tree was permitted to get into an advanced condition of die-back, so that practically every cherry examined showed beans breaking down. Since the soil was dry, a 500 gm. lot of ammonium nitrate was applied in solution and well watered in. A similar quantity of water was applied to another chlorotic tree. A month later both trees were still chlorotic, but in the tree that

had been treated with nitrogen die-back was arrested and all beans were full; in the other die-back was proceeding actively and there was well over 60 per cent. of empty beans. The ripened crop from the treated tree gave a good out-turn of clean coffee; the crop on the untreated tree failed to ripen; it dried on the tree. The treated tree soon produced new growth and was fit to carry a crop next season. The untreated tree suffered from very severe die-back, lost many of its primaries, and was incapable of carrying a crop next season; in fact, it was necessary to stump the tree.

The roots of many trees suffering from nitrogen-deficiency, chlorosis, and die-back have been examined. In no case has there been any recognizable death of the roots. Fig. 2 (Plate 13) is a diagram of the root-system of a coffee-tree which the year previously had suffered from severe chlorosis and die-back. Sections cut of main lateral roots of trees in a state of die-back have always been found to contain large quantities of starch granules. The simpler test of putting iodine on a cut surface has always been positive for starch.

Chlorosis due to inadequate carbohydrate-supply.—The early stages of this form of chlorosis are very similar to those described above. The colour, however, is more of a buff yellow than lemon yellow, but it is very difficult to differentiate between the two colours, other chlorosis-effects being liable to complicate matters. A marked difference occurs when the apical leaves die. Death of the twig begins not from the terminal bud but from the point where green immature wood starts; perhaps three internodes will collapse and die. The dead apical leaves may be retained for some weeks before they finally drop. The branch then dies back in exactly the same way as before. Die-back may sometimes involve the whole tree.

The crop in this form of chlorosis and die-back does not suffer. The cherry is always full; even the cherries on the apical part of a shoot, which has died back early in the development of the bean, will contain some residue of a bean and not merely a shrunken residue. The crop that ripens—the full red colour does not develop—is always full and a normal output of clean coffee is obtained.

Die-back and chlorosis of this type is always accompanied by severe die-back of the roots. Laterals may die back to the main root-stock, leaving only a scar. Figs. 3 and 4 (Plate 14) illustrate the root-system and root-stock of a tree which had suffered severely from this form of chlorosis and die-back. The residue left after death is peculiar and consists of white, easily-powdered material, reminiscent of the texture of wood attacked by dry rot. One only rarely finds this residue on account of termite action, but in every case where the writer has found remains of dead roots on a tree that has suffered from carbohydrate die-back, they have been of this dead-white, easily-powdered type. Main roots which have died from other causes are usually brown and very hard.

Many trees suffering from this form of die-back have been examined and in no case has a positive test for starch been obtained. Roots, wood, and even young leafy shoots have all given negative results. The conclusion to which one is forced is that this type of chlorosis and die-back is

simply overbearing beyond the capacity of the tree, and that the tree, in order to carry the crop, mobilizes all its carbohydrate-reserves in the attempt. It appears from the die-back of the roots and the residues found, that there must be very complete mobilization of the carbohydrates, even structural materials being used so far as possible.

The application of nitrogenous fertilizers to trees dying back is of no use at all. An early application of a nitrogenous fertilizer when the crop sets or the first signs of chlorosis appear, by increasing leaf-growth, may either prevent this form of chlorosis completely or make the attack very mild.

In the year 1934, owing to long-continued drought conditions, during which photosynthesis was depressed, the carbohydrate-reserves of the trees were depleted and this type of chlorosis was very widespread. Normally, however, in Kenya it has been dominant only in those districts where the natural vegetation is the orchard bush-tall grass complex. Whether the soil and climatic conditions which have given rise to this vegetation climax are conducive to poor carbohydrate-synthesis, it is too early to say, but the occurrence is at least suggestive. Even in these areas it is noticeable that in plantations where good farming practices are employed chlorosis is absent or very faint.

This form of chlorosis and die-back is considered to be the more serious. Although a fair crop is obtained from trees in a state of die-back, the loss of most of the roots prevents the trees from being anything more than passengers for at least two years. The type of cropping Sanders and Wakefield [3] call 'biennial' and 'triennial' bearing develops, a fair crop is followed by one or two light crops. The yields in one plantation where this type of die-back is common are as follows (cwt. per acre): first year 6·4, second year 2·9, third year 6·7, fourth year 1·9; an average over the last three-year period of just under 4 cwt. per acre. Compare with this the average 6·8 cwt. per acre from a neighbouring plantation where during the last three years chlorosis and die-back have been reduced to a minimum by good farming practices and rational manuring. The plantation quoted is very much above normal for the area; there are many plantations where the effect has been very much worse. On one, the year after their first crop the trees were all chlorotic, had put out no new growth, and possessed hardly any lateral roots; root-scars showed that the trees had possessed a fair root-system before the crop was carried. On another, so severe was the effect that the owner uprooted the whole block as being unlikely to be economic.

The loss of crop on a tree suffering from chlorosis and die-back due to nitrogen-deficiency is immediately serious, but the tree very quickly recovers, especially if it is properly manured, and is soon in a fit state to carry a crop.

Other forms of chlorosis due to physiological causes.—Often the terminal leaves of coffee are found to be an even bright yellow, and, in extreme cases, malformed and twisted. This condition has been termed climatic chlorosis [1], and was thought to be due purely to climatic extremes, such as rapid temperature changes, or to sudden major weather changes. But when it was found that the young leaves of trees liable to this form of chlorosis were scorched by kerosene oils that had no effect upon

normal foliage, it was realized that there was some reason for this tenderness to climatic variation.

Among various contributory causes which have been recognized as conducive to the condition are all those which throw a strain upon the tree. Trees which are recovering from carrying an excessive crop are very likely to produce young leaves that are very sensitive to weather conditions. It is very rare to see anything but misshapen, torn, and twisted leaves on the exposed top of such a tree. The leaves produced after defoliation by caterpillars are very tender and liable to become chlorotic and malformed. Strain is not the only factor. The upper leaves of a single-stem tree, pruned into a very flat-topped form, are all liable to develop this form of chlorosis. At present it is not possible to adduce any hypothesis accounting for the production of tender leaves. At the best it can only be recognized as a condition indicating that something is wrong.

Another type of chlorosis, which is frequently encountered, especially common in trees growing on old stock *boma* (pen) or hut sites, has also defeated attempts to elucidate its ultimate cause. The veins here remain dark green against the yellow background of the leaf-blade, similar to the early stages of sulphur-deficiency chlorosis in tea, described by Storey and Leach [7].

The leaves showing this form of chlorosis are larger than usual and very soft. They contain 23 per cent. of dry matter as compared with the 35 per cent. of normal leaves. The iron-content too is especially low. It thus appeared that here one was concerned with some deficiency-disease. The soil on these old occupied sites is always less acid than the normal, the surface-soil often having a pH value above 7, as compared with the more normal, 5·5–6. It is also very rich in available phosphates, as shown by the Illinois Field Test. Heavy applications of unbalanced fertilizers and salts of many of the trace elements with and without sulphur have been applied to trees showing this form of chlorosis, without any effect upon the disease.

It has also been observed that often the young shoots on trees which have been stumped develop leafage showing this form of chlorosis. It is highly unlikely that under such conditions a mineral deficiency should be the cause of the chlorosis; the ultimate cause must be sought elsewhere. It is, however, suggestive that it does predominate on land which has been occupied by natives as stock *bomas* or as hut sites.

Summary

1. Four forms of chlorosis in coffee are described which are attributed to physiological derangements.

2. One form is ascribed to an inadequate supply of nitrogen at the period of maximum demand. It is usually accompanied by die-back and involves severe loss of crop. In this form there is no death of roots. Application of nitrogenous manures arrests loss of crop and die-back.

3. Another form, very similar in appearance, is attributed to a deficient carbohydrate-supply. It is accompanied by severe die-back both of branches and roots, but usually a fair crop is produced. Nitrogenous

FIG. 1. Sections across green coffee cherry, showing successive stages in breaking down of bean

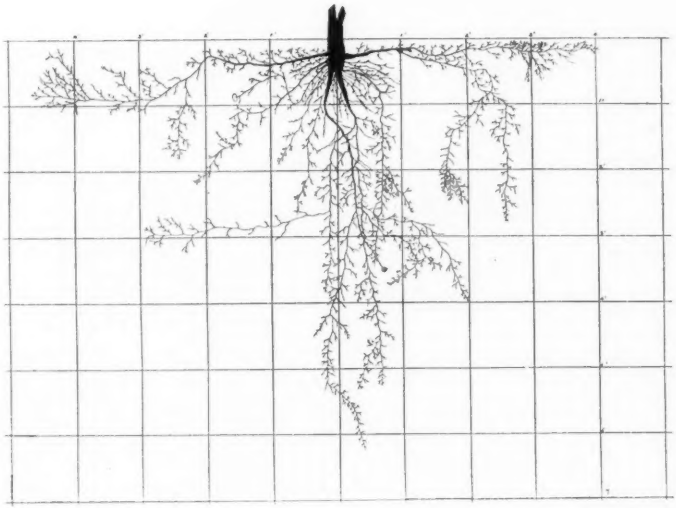

FIG. 2. Diagram of root-system of a coffee tree which had suffered severe nitrogen die-back. (1 ft. squares.)

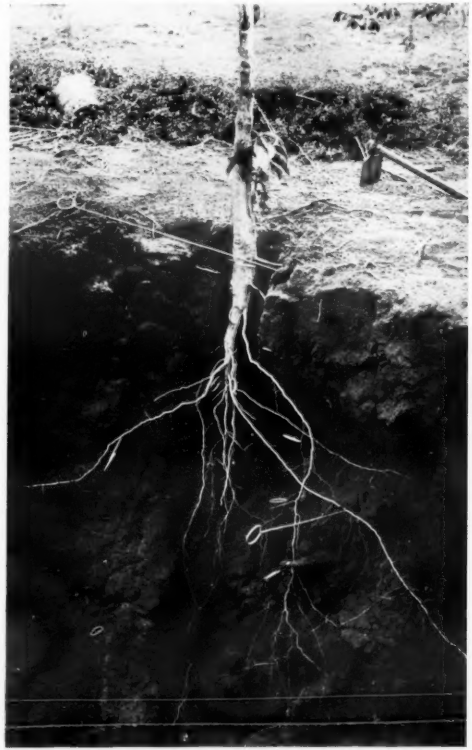

FIG. 3. Root-system of a coffee tree which has suffered severe carbohydrate die-back

FIG. 4. Enlarged view of top of root-system of tree in Fig. 3, showing root-scars, dead roots, and developing adventitious root

manuring, unless applied very early, has no effect upon this form of die-back.

4. Two other forms have been recognized but it is not yet possible to attribute them to any definite causes.

REFERENCES

1. V. A. BECKLEY, The Yellowing of Coffee. Kenya Dept. of Agric., Bull. No. 3 of 1931.
2. F. R. SANDERS and A. J. WAKEFIELD, Coffee Cultivation. Pamphlet No. 7, Tanganyika Territory Dept. of Agriculture, 1932.
3. — — Further Observations on Factors in *Arabica* Coffee Culture. Pamphlet No. 8, Tanganyika Territory Dept. of Agriculture, 1932.
4. A. J. WAKEFIELD, *Arabica* Coffee: Periods of Growth and Seasonal Measures. Pamphlet No. 9, Tanganyika Territory Dept. of Agriculture, 1933.
5. F. J. NUTMAN, 6th Annual Report 1933–4, East African Agricultural Research Station.
6. V. A. BECKLEY, Some Symptoms of Plant-nutrient Deficiencies in the Coffee Tree. J. East Af. & Ug. Nat. Hist. Soc., 1931, **38/39,** 10.
7. H. H. STOREY and R. LEACH, A Sulphur-deficiency Disease of the Tea Bush. Ann. App. Biol. 1933, **20,** 23–56.

NOTE. Since the above was written the writer has been able to obtain Nutman's paper, 'The Root-System of *Coffea arabica*, Part II: The Effect of some Soil Conditions in modifying the "Normal" Root-System' (*Empire J. Expt. Agric.*, 1933, **1,** 285), in which he discusses the effect of die-back on the root-system. The effect of die-back of roots converting a normally deep-rooted tree into a surface-feeder has not been observed in Kenya. In every case where die-back has been severe all the roots have been involved and, as can be seen from Fig. 4, surface laterals are often completely aborted. With this exception carbohydrate die-back follows the same course in Kenya as described by Nutman.

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OBSERVATIONS ON COFFEE IN KENYA

Pt. II. VEGETATIVE PROPAGATION OF COFFEE

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With Plates 15, 16

ONE of the first things noticed in any coffee plantation in Kenya is the extremely variable population. This is due to the heterogeneous nature of seedling material; even that from a 'selfed' tree shows marked variations. There are two methods by which this variation could be overcome, by breeding and by vegetative propagation. The breeding of pure lines of coffee seed is very slow and entails many years' work covering several generations; it is therefore unsatisfactory. In consequence, some three years ago, our attention was drawn to the second method. At that time much success was being obtained with the reproduction by asexual means of other tropical crops, and it was considered that it might also be applied to *C. arabica*. It is here proposed to deal with the work which has been conducted to date.

Many possible methods of vegetative propagation have been under experiment, the results of which are dealt with under their separate headings. It should be noted that, owing to the marked polarity of coffee, all material used for cuttings or as scion wood for grafting is taken from vertical growth. Lateral wood produces only low-growing, flattened trees.

Cuttings.—It is of the greatest interest and importance to note how very closely results obtained here with coffee correspond to those obtained with cacao in Trinidad [1]. With the exception of slight variations in technique, the raising of clonal material of these two crops appears to be closely related and thus any further work conducted in Trinidad should be followed closely by those working with coffee.

Whilst the grafting of coffee has been practised in some countries, notably Java [2, 3] for many years, it is remarkable that so little work has been conducted on the propagation of coffee by cuttings. This may be due to the belief that cuttings do not produce good root-systems, or that they do not have the traditional tap-root of the seedling. That the seedling seldom produces a true tap-root but relies on a number of deep-rooting verticals is now proved, so no importance can be attached to this theory. The former suggestion is a possibility which cannot be overlooked and merits further investigation. The results of the experiments so far, nevertheless, indicate that the root-system of a 'cutting' compares very favourably with that of a seedling tree (Figs. 1 and 2, Plate 15) and that trees 2–3 years old raised from cuttings, are comparable with seedling trees of the same age. (Figs. 3 and 4, Plate 16.)

(*a*) *Hardwood.*—At the Scott Agricultural Laboratories, Nairobi, where most of the early work has been carried out, many hundreds of different types of hardwood cuttings have been planted out in open nurseries without success. In another district in Kenya with very different

climatic conditions—heavier rainfall being possibly the chief factor—a coffee planter has been highly successful with this type of cutting, the material used being prunings from trees grown on the Multiple-Stem system. Each cutting was approximately 2 ft. long and about 1–1½ in. in diameter. How these cuttings will behave when they become mature trees must await further investigation, but it is interesting to note that they are already producing a prolific root-system.

(*b*) *Softwood.*—The propagation of this type of cutting entails the use of a closed frame or propagator. Several different propagators have been tested. That which is most suitable to local conditions consists of frames artificially heated by ordinary 'hurricane' lamps in chambers beneath and with a canopy overhead. Sand, thoroughly washed and steam-sterilized, is used as the rooting medium.

The type of cutting is of the utmost importance. That which has given the greatest success, although termed softwood, really consists of a tip, having semi-hardwood at the base and allowed to retain its young tip leaves. The cutting used is 6–9 in. long and not more than ¼ in. in diameter. Very suitable material will often be found growing as a bunch of suckers on a stumped tree, generally in the centre under dense shade. Attempts are now being made to induce this type of growth on a larger scale by various methods—shading, &c. Since the tip leaves must be retained, a high humidity must be maintained in the propagator and thus the frames are opened up for a few minutes only each morning. The rooting-medium, which is kept at a temperature between 68° and 72° F., requires watering about twice a week; on the other mornings the leaves of the cuttings are subjected to a fine spray of water in order to keep them fresh. Rooting may be expected in 3 to 4 months. Attempts have been made to stimulate the initiation of root-growth by treating the cuttings with certain gases [4 and 5] prior to placing them in the propagators, but so far no success has been recorded.

(*c*) *Root and leaf cuttings.*—All attempts to propagate these types of cuttings have failed.

(*d*) *A modified form of layering.*—Both correct layering and marcotting gave success during the first experiments conducted, but owing to the tedious nature of the work, and the slow rate at which it would be possible to raise large clonal populations, other methods were sought. Early work proved that if suckers, growing from an old stumped tree, were ring-barked near the parent stump and then etiolated, they would root with comparative ease, provided suitable weather conditions prevailed. This indicated that if some method could be found whereby the parent material could be made to produce a larger area for the production of sucker-growth, little difficulty would be experienced in raising large clonal populations. Thus a technique has been evolved and whilst, owing to drought conditions, only early observations can be recorded, it is satisfactory to note that these are most hopeful. The following is the method adopted. A rooted cutting from a selected tree is planted out in a nursery at an angle of approximately 25 degrees from the horizontal. By keeping it pegged down, it will continue to grow in this plane. As this plant grows, suckers come away from the axillary buds. When

about 12 in. high they are ring-barked at the base and soil banked round them. When rooted, the soil is removed and the sucker cut away from the parent plant, which again will produce further cycles of suckers for similar treatment. In the first cycle only a few of the rooted suckers should be removed, the remainder being pegged over at right angles to the original plant to provide a larger area for the production of rooting-material in the second and subsequent cycles. Experimentation has shown that earthing up must not be carried out until the suckers are ready for rooting, and even then it is necessary to ring-bark each sucker.

Budding.—When the study of the vegetative propagation of coffee was started, considerable attention was given to the possibilities of budding, but as it has been found that the technique presents several difficulties, the method has been abandoned in favour of grafting. It is of interest to note that in referring to budding, Marshall [6] says: 'The union of stock and scion is much weaker than when grafting is used. In heavy wind the entire growth is liable to break back to where the original bud was inserted.'

Grafting.—Grafting has been widely used in Java where, due to the self-sterility of *robusta* coffee, decreased yields have always been recorded from monoclonal plantations [7]. This difficulty is now being overcome by the interplanting of different clones or by the introduction of a number of seedling trees. Fortunately, *arabica* coffee, being a self-fertilized plant, will not present the same problem. Considerable success has already been achieved with different methods of grafting in Kenya.

Grafting by inarching.—Methods of inarching young seedlings in the nursery and of inarching one-year-old plants upon old stumped trees in the field was first attempted with considerable success by Rogers, Superintendent of Plantations, at Amani [8]. His methods have been successfully adopted here and it would appear that either system is an easy way of grafting one variety of coffee upon another (*arabica* on *robusta*). Unfortunately with this method both scion and stock must be seedling material, an arrangement by which little ultimate gain can be obtained.

Cleft-grafting.—Most attention has been paid to this form of grafting, as by this method it is possible to graft clonal scion-material upon seedling stocks. Large numbers of grafts have been made in establishing a technique which gives a high percentage of successful unions. From observations made in the progress of this work the following conclusions have been made regarding the technique:

(*a*) The larger the stock and scion the easier it is to make a successful graft. Seedling stocks about 18–24 months old are much easier to graft upon than younger material.

(*b*) The stock should be cut just above or across a node and a cleft about 2 in. deep made between the buds.

(*c*) The scion is cut in the form of a wedge beginning on either side of a bud.

(*d*) The scion wood must be active at the time of grafting.

(*e*) The protection, which must be applied to prevent movement between the stock and scion until union has been made, should vary

according to the time of the year at which the graft is made. It has been found that the best time of the year for grafting at the Scott Agricultural Laboratories is during the cool, dry weather (June–October). In June, when sap flows freely from the stock, it will be advisable to bind the graft with gunny string only. Later in the season, at a time when there is little sap flowing and the weather is warmer, all cut surfaces, including the tip of the scion, should be protected with grafting wax.

(*f*) In all cases the whole graft should be protected for a period of about three weeks by covering it with a loose waxed-paper cover.

Grafting in the field upon old stocks.—All attempts at rind-grafting upon old stocks proved unsuccessful, so that other ways had to be exploited. The method adopted, which is proving successful, is that of grafting on sucker-growth encouraged from the base of the tree. When the sucker has obtained sufficient size and maturity it is treated in precisely the same manner as are seedling stocks in the nursery. The ordinary cleft-graft is made as described above and is waxed and covered with a paper cover as before. The tree may be stumped back to the sucker either before grafting or afterwards. If it is left until after grafting the natural shade thus formed will assist the newly made graft in its early days. Care must nevertheless be taken to stump before the graft makes too much growth or it will be drawn up and tend to become whippy. The growth of a graft on an old-established root-stock is remarkably rapid.

Sufficient work has been carried out to show that coffee can be reproduced successfully by asexual means in Kenya. It would not be wise, however, to recommend it for field practice before further experiments have been conducted to study the many problems involved in mass reproduction.

Among those which have already been forced to receive attention is the relationship between stock and scion and the effect of root-stocks of other *Coffea* species upon *C. arabica*. The behaviour of mature trees produced vegetatively deserves close attention and must be compared with trees raised from seed, both as regards variations in habit and in yield.

Acknowledgements

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REFERENCES

1. E. E. CHEESMAN, The Vegetative Propagation of Cacao. Empire J. Expt. Agric., 1934, **2**, 40–50.
2. F. P. FERWERDA, Vegetative Propagation of Coffee. Empire J. Expt. Agric., 1934, **2**, 189–99.

3. D. J. S. CRAMER, Early Experiments on Grafting Coffee in Java. Empire J. Expt. Agric., 1934, **2**, 200–4.
4. P. W. ZEMMERMAN, WILLIAM CROCKER, and A. E. HITCHCOCK, Initiation and Stimulation of Roots from Exposure of Plants to Carbon Monoxide Gas. Contributions from Boyce Thompson Institute, **5**, no. 1.
5. P. W. ZEMMERMAN and A. E. HITCHCOCK, Initiation and Stimulation of Adventitious Roots caused by Unsaturated Hydrocarbon Gases. Contributions from Boyce Thompson Institute, **5**, no. 3.
6. T. H. Marshall, Coffee Grafting and Budding. Dept. Agric., Tanganyika Territory.
7. F. P. FERWERDA, Grafts *v.* Seedlings in Coffee. De Bergcultures, 1932, **6**, 629–44.
8. F. M. ROGERS, Report of the Superintendent of Plantations, Amani. Sixth Annual Report, 1933–4.

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THE EFFECTS OF VARYING AMOUNTS OF ANIMAL PROTEIN FED TO WHITE LEGHORN PULLETS

Pt. I. THE INFLUENCE OF LOW-, MEDIUM-, AND HIGH-PROTEIN DIETS ON THE WEIGHT AND NUMBER OF EGGS[1]

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THE special interest now being shown in the weight of the eggs laid by individual birds, due to the greater economic value of the large egg, is reflected in the many experiments that have been made to study the various factors affecting both the number and weight of eggs that a bird lays. Studies are also reported of attempts to increase the weight of eggs above the normal size produced under normal conditions by a conditioned management and feeding of the hens.

Atwood [1] published data showing that liberally fed hens produced larger eggs than scantily fed hens, and unbalanced rations tended to reduce the size of eggs, i.e. the effect of normal and subnormal rations.

Nils Hansson [2] of Sweden, starting out from the standpoint that their extensive experiments with dairy cattle had given them definite results regarding the protein-requirements for production, used those results in computing rations for their studies (carried out simultaneously at three stations) on the protein-requirements of laying hens. He concluded that the optimum protein-content of a ration lies between 120 and 130 gm. digestible protein per feed-unit, provided the protein had a satisfactory biological value. He also observed that during heavy laying-periods, and also during colder weather, larger amounts of feed were necessary. Optimum protein rations caused a slightly better numerical egg-production than rations outside the optimum; the author, however, did not show the statistical significance of the difference. The various amounts of protein did not result in a difference in the average size of egg.

W. R. Graham, Jun. [3], in an experiment where the effect and value of various protein-supplements were compared, concluded that the differences in mean egg-weight that occurred were entirely without statistical significance.

Rice, cited by Curtis [4], showed that the number of eggs produced by a flock was positively correlated with the amount of feed consumed, and the fluctuations in amount of feed consumed were characteristic of the seasonal fluctuation in egg-weight.

Fangauf and Kallmann [5], in comparing two groups, one having a protein-carbohydrate balance of 1 : 3 and the other self-fed, showed that the self-fed birds varied the ratio according to the month of the year. During the experimental period November to July the self-fed group,

[1] Published by permission of the Principal, College of Agriculture, Stellenbosch, Union of South Africa.

during the months of highest protein-intake, balanced to 1 : 1·6; during March, April, and May to 1 : 3·1; and during July 1 : 4·7. No difference in egg-production of the two groups was observed. The normal group showed higher increases of body-weight.

Byerly, Titus, and Ellis [6] fed single-comb Rhode Island Red pullets with a basal ration to which was added 20 per cent. of protein-supplement in the form of feeds rich in animal- and vegetable-derived protein. They found a positive correlation of $r = 0{\cdot}226 \pm 0{\cdot}0347$ between percentage of protein in the diet and percentage production after first egg. They cite Kempster's [7] correlation between the same factors as $r = 0{\cdot}5179 \pm 0{\cdot}071$. The coefficient of correlation between percentage of protein in each diet and egg-weight is $r = 0{\cdot}339 \pm 0{\cdot}0317$. The conclusions from the above are that the percentage protein between the limits of 11 and 24 per cent. has a definite effect in that it increases the weight and number of eggs.

Parkhurst [8] found that varying amounts of protein in a ration, when the mineral-content remained the same, did not have any significant effect on the egg-size, and a complex protein was as ineffective as a simple one in increasing egg-size. Further extra amounts of skim-milk powder fed to crossbred pullets did not materially affect egg-size.

Material and methods of the experiment.—In the experiment described in this paper 60 South African White Leghorn pullets were used. They were divided into 3 groups of 20 each. Each group contained individuals of similar weight when the experiment began (Nov. 28, 1931).

All the birds were bred from four matings containing related blood lines and were hatched during July-August 1931. The pens were of the intensive type, the birds running on cement floors covered with oat-straw litter, which was replaced on the same day each week. These pens were covered on the one side with $\frac{1}{2}$ in. mesh wire-netting from 2 ft. above the floor to the roof. The open side faced north-north-east, so that sunlight was admitted from shortly after sunrise until fairly late afternoon, even in winter. The College Farm is situated in the winter-rainfall area of the Union; also the poultry division is laid out on low ground at the base of a hill, consequently the birds experienced a considerable amount of morning mist and rain during autumn and winter. Trap-nests were provided in each pen and were visited approximately each hour during the main laying-period of the day. Each bird was retained in the experiment, and the eggs were recorded for 365 days from the date the first egg was dropped. The pullets were selected prior to reaching maturity. Three months after the commencement of the experiment three birds were culled which, although matured, had not begun to lay, whilst two other birds which had just started to lay died of apoplexy during a 'heat wave' experienced about the middle of February.

All eggs were weighed at 4 p.m. on the day laid to the nearest 1/32nd of an ounce. Eggs laid after this time were collected and weighed after the final trap-nest inspection towards evening. For all three groups a basal mash ration was used which consisted of bran, 40 lb., pollard, 35 lb., yellow mealie meal, 10 lb., Sussex oats, 12 lb., and bone-meal, 3 lb.; total 100 lb. To this basal ration $2\frac{1}{2}$ per cent. by weight of blood-meal

was added to Group 1 (low-protein), 10 per cent. by weight to Group II (medium-protein), and 25 per cent. by weight to Group III (high-protein).

The grain fed to all three groups consisted of crushed yellow maize. Fresh separator milk was supplied each morning, and water, grit, shell, and charcoal were always available in the pens. The mash feed was fed in the dry state in self-feeding hoppers, which were standing in trays, so that any waste could be collected and deducted from the total feed consumed. These hoppers were left open from daylight until 3.30 p.m. At 4 p.m. the grain feed was fed in shallow trays, which were placed in the larger trays so that any material spilt might be collected. The birds were allowed access to this grain for about an hour. The separator milk was measured each morning before being supplied to the birds, and what remained at 3.30 p.m. was measured and deducted from the daily amount fed. The average analysis of the mash feeds used including the protein supplement was:

	Crude protein
	Per cent.
Group (1), low-protein . . .	15·61
Group (2), medium-protein . . .	20·31
Group (3), high-protein . . .	29·06
Maize	9·50
Separator milk	3·39

Experimental results.—All the data obtained have been graphically presented and comprise graphs showing the following relationships:

1. Average amount in gm. of mash eaten per bird per month for each group.
2. ,, ,, gm. of grain eaten per bird per month for each group.
3. ,, ,, c.c. of milk drunk per bird per month for each group.
4. ,, ,, gm. of protein eaten per bird per month for each group.
5. The protein-carbohydrate ratio of feed and milk consumed each month.
6. Average number of eggs produced per group per month.
7. Average weight of eggs produced per group per month.
8. Average body weight of each group per month.

The amounts of feed eaten each month.—Figs. 1, 2, 3, showing the amounts of mash, grain, and milk taken each month and calculated per bird for each group, when these feeds are self-fed, clearly indicate that the amount of feed consumed depended almost entirely on the kind and composition of the feed itself and the month of the year.

Examining Fig. 1, one notices that the mash was taken by all three groups according to the amount of protein that it contained. Group I birds, which had access to a mash of a comparatively low-protein content, ate a larger amount than either Group II or Group III, whilst Group II again having been fed with a mash with a higher-protein content than Group I and a lower-protein content than Group III, ate more each month than Group III. The difference in amounts of feed eaten are also brought out in Table 1, showing the average amounts of feed eaten per bird per day for each group during the thirteen months that the experiment lasted.

Of special interest is the consumption of the mash during the various months of the year. Although there was a difference in the amount consumed by each group during each month, there was a striking similarity between the relative amounts consumed during each month during the

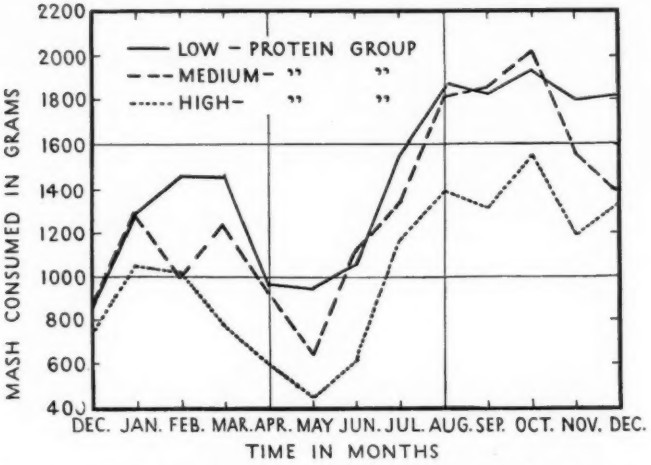

FIG. 1. Amount in grams consumed per bird per month of mash of low-, medium-, and high-protein content.

course of the year by the various groups. The parallelism of the three graphs is only broken badly during February, when for an unaccountable reason the medium-protein group consumed a quite disproportionately small amount of mash. No reason can be found for this deviation from the apparently normal consumption. Peaks of mash-consumption occur during the months of January, February, and March, and then again later in the year during August, September, and October. Low consumption, on the other hand, takes place during April, May, and June.

TABLE 1. *Average Amount of Feed taken per Bird per Day for each Group*

Group	*Mash Amount per bird per day*	*Grain Amount per bird per day*	*Separator Milk Amount per bird per day*
	gm.	gm.	c.c.
Group I . .	49·4	39·2	101·8
Group II . .	45·5	39·8	108·5
Group III . .	35·5	43·2	127·9

Fig. 2, which shows the amount of grain consumed during the thirteen months, portrays quite a different attitude of the birds to the grain. Comparatively, the amounts of feed taken are fairly similar, with a somewhat higher consumption by the high-protein group. The average

amounts of the whole experimental period, as shown by Table 1, are 39·2 gm., 39·8 gm., and 43·2 gm. for Groups I, II, and III, respectively.

In contrast with the mash-consumption there are no consistent fluctua-

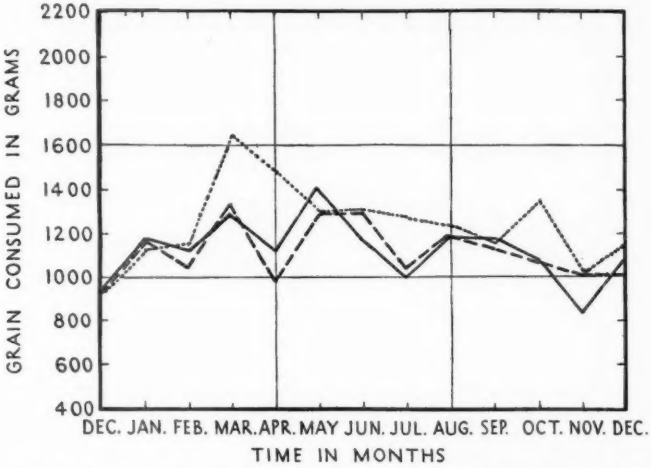

FIG. 2. Amount of grain in grams consumed per bird per month by the low-, medium-, and high-protein groups.

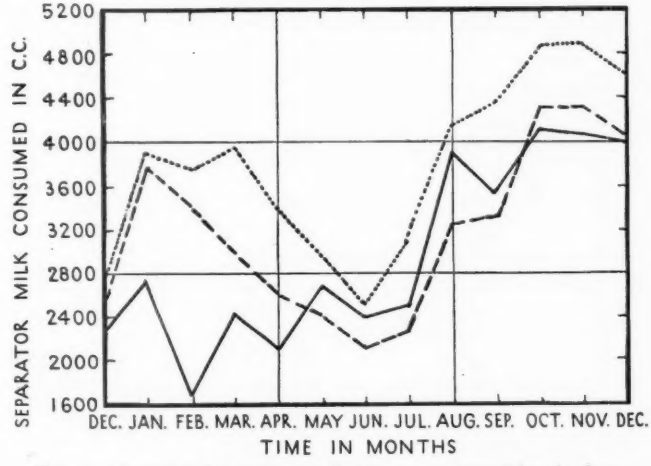

FIG. 3. Amount of separator milk in c.c. consumed by the low-, medium-, and high-protein groups.

tions during the various months of the year, with definite high and low peaks. During March and April and again in October the high-protein group shows a definite larger intake of grain. The tendency indicated is for the higher-protein group to take a larger amount of grain to balance

the mash containing the higher protein, whilst the low-protein group tends to take a larger amount of mash to balance the grain rich in carbohydrate.

There is certainly a tendency for the birds, when self-fed, to select their feeds in such a way that the resultant mixture consumed has neither a too high nor a too low protein-carbohydrate ratio.

When studying Fig. 3, viz. the separator-milk consumption per bird per month, one notices less consistent tendencies than in Figs. 1 and 2. Although birds in Group III consistently consume more separator milk than do those in Groups I and II, the graphs of the latter show no con-

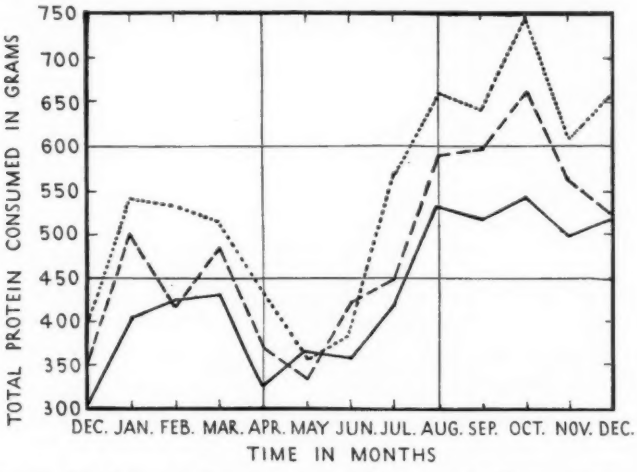

FIG. 4. Total amount of protein in grams of feed and milk consumed per bird per month of the low-, medium-, and high-protein groups.

sistent difference one way or the other. The average over the experimental period is 101·8 c.c., 108·5 c.c., and 127·9 c.c. for the low-, medium-, and high-protein groups.

Protein taken by the various groups.—Fig. 4 represents graphically the total amount of protein taken per bird, month for month, calculated from the analysis of the three kinds of feed provided.

Although all three feeds were self-fed and the birds showed a selective power to balance their rations towards a common protein-carbohydrate ratio, Fig. 4 shows that there was a definite difference between the amounts of protein taken by each group during the experimental period. The differences in protein-intake are largest during the months when the birds are consuming large amounts of protein, but during the months when comparatively small amounts are taken there is no significant difference. The average amount of protein taken per bird per month during the thirteen months for Groups I, II, and III are 434·8 gm., 481·8 gm., and 542·2 gm. respectively. Expressed as percentage differences the medium-protein group took 10·81 per cent. more protein and

the high-protein group 24·70 per cent. more protein than the low-protein group, whilst the high-protein group consumed 12·54 per cent. more protein than the medium-protein group (Table 2).

TABLE 2. *The Average Amount of Protein taken per Bird per Month and the Percentage Differences*

Group	*Average amount of protein per bird per month*	*Percentage difference in amounts between*		
		Groups I and II	*Groups II and III*	*Groups I and III*
	gm.			
Group I . .	434·8	10·81	12·54	24·70
Group II . .	481·8	..	..	..
Group III . .	542·2	..	..	..

Fig. 4, just as Fig. 1, shows that there is a striking similarity in the course of the curves of the three groups. All three follow one another very closely with the exception of the sudden drop during February depicted by Group II. High peaks of protein-consumption are evident during August, September, October, November, with the highest point in October. Lowest protein-consumption occurs during April, May, and June. As was to be expected, these graphs follow very closely those of the amount of mash eaten, as the mash being the largest source of protein of the feeds would most largely affect protein-consumption.

Protein, total carbohydrate ratio.—The total protein was calculated from the analysis of the various feeds, but in the absence of complete analysis the amount of carbohydrates was obtained by accepting existing analysis of the same kind of feed as being applicable to the consignments used in this experiment. Although the figures of total carbohydrates on which Fig. 5 is based have not the basis of exact chemical analysis, we are convinced that Fig. 5 is sufficiently correct to show the general trend of nutritive ratios, and from which tentative conclusions can be drawn.

Typical extremes of ratios have been selected and are presented in Table 3.

TABLE 3. *Ratios of Protein to Total Carbohydrates of Feeds taken during February, May, and October by the Three Groups, and the Average of the Whole Period*

Group	*Ratio of protein to total carbohydrates during*			
	February	*May*	*October*	*Whole period*
Group I . .	1 : 5·05	1 : 5·42	1 : 4·66	1 : 4·96
Group II . .	1 : 4·57	1 : 5·41	1 : 3·96	1 : 4·43
Group III . .	1 : 3·35	1 : 4·29	1 : 3·14	1 : 3·45

Examining Fig. 5, it is again evident that there are large differences in the ratios established by the various groups of birds. Only during May do Groups I and II approach one another. Table 3 shows the high and low ratios as occurring during February, May, October, and the average

over the whole period. This average value also shows comparatively large differences ranging from 1 : 4·96, 1 : 4·43, to 1 : 3·45 for the low-, medium-, and high-protein groups respectively.

The graphs are strikingly similar in form except during May and June, when Group II takes an apparently abnormal large amount of carbohydrates as against protein. Further, each graph can be divided into three definite periods, viz. a medium ratio during December, January, and February, a high ratio during March, April, and May, followed by a sharp fall during June and July reaching and maintaining a comparatively low ratio during the remaining months of August, September, October, November, with again an upward tendency during December. Grouped in seasons one could conclude that during autumn, spring, and summer there is a low carbohydrate-consumption in proportion to the protein-consumption, followed by a complete reversal during the winter months.

Influence of feeds on numerical production and egg-weight.—Fig. 6 shows the monthly production of eggs by each group, based on an even number of 18 birds in each group. It is immediately evident that whatever the difference in numerical production from group to group, the difference is not significant. Table 4, however, gives a better idea of the difference, but unfortunately also no true reflection for the following reasons:

TABLE 4. *Difference in Numerical Production calculated on an Even Number of Birds in each Group*

Group	*Eggs laid outside traps*	*Total no. of eggs per group*	*Av. no. of eggs per bird*	*Av. no. of eggs per bird excl. eggs laid outside traps*	*Diff. in no. of eggs per bird excluding eggs laid outside traps*
Group I	214	3,332	175·3	164·5±5·480	Groups I and II 10·1 ±8·216
Group II	113	3,248	182·3	174·6±6·121	Groups II and III 9·8 ±7·545
Group III	89	3,409	189·4	184·4±4·412	Groups I and III 19·9 ±7·036

Column 2 shows that a number of birds laid eggs outside the traps. This took place at the beginning of the experiment, when the hens had not yet become accustomed to the experimental pens, and when the attendant was still inexperienced. These eggs, together with the recorded eggs, are given in column 3 and divided by the number of birds in each group, as shown in column 4. There being no accurate method of attributing these eggs to the hens that laid them, only eggs recorded to the birds were used in calculating column 5. Because of the eggs laid outside the nests the averages shown in column 5 are lower than the correct average, and owing to the differences in these numbers Group I is affected more than Group II and the latter more than Group III. Consequently it was argued that should no significant difference be shown with the recorded eggs in favour of the higher-protein groups, certainly less would be shown if the eggs laid outside the traps could be allocated to the rightful owners.

As previously shown in Table 2 and Fig. 4, Group I consumed less protein than Group II, and the latter less again than Group III. No significant difference in number of eggs is apparent from Table 4 between

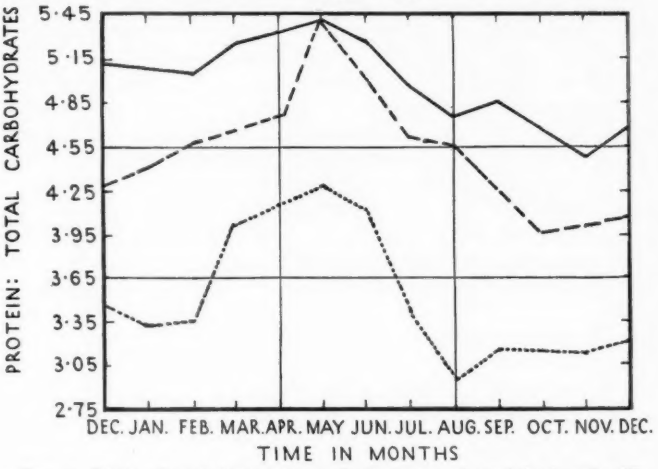

FIG. 5. Ratio of protein to total carbohydrates of total feed and milk consumed by each group each month.

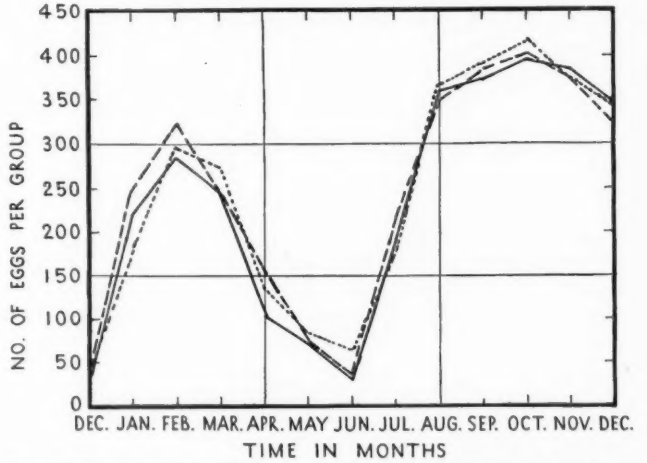

FIG. 6. The average number of eggs produced by the low-, medium-, and high-protein groups each month, calculated on an even number of 18 birds per group.

Groups I and II and between Groups II and III, as the difference in each case is less than twice the standard error of the difference. The outside trap eggs, if correctly recorded, would decrease still further, whatever significance there was.

Comparing Groups I and III, where there is a comparatively very large difference in protein-consumption between the groups, the difference in recorded eggs is significant. It is impossible to conclude, if the eggs were all correctly recorded, that there would still be a significant difference, as the averages per bird of the total eggs differ only by 14·1, whilst the difference of recorded eggs is 19·9. How the standard error would be affected by a correct recording is impossible to estimate.

The progressive increase in numerical production with increases of protein-intake would, however, suggest the conclusion that a protein-increase within certain limits carried out with a larger number of hens, of more uniform laying-capacity, would possibly increase their numerical production, although this fact is not conclusively proved by this experiment.

The curves showing the monthly production of eggs for the three groups (Fig. 6) reveal a most striking similarity. High and low peaks fall during the same months, and the same course is followed throughout by each curve. The seasonal effect is also definitely established. All three groups show high production during January, February, and March, i.e. in autumn, and again during August, September, October, and November, i.e. in spring and early summer. Low production occurs during the rainy winter months, April, May, June, and July.

Graphs 4 and 6, showing monthly protein-consumption and monthly production respectively, reveal such a marked correspondence that one can infer that as the protein-consumption increases over a certain period the numerical production increases over the same period. Keeping in mind that the natural influence to produce periodically has not been completely overcome by breeding and management, i.e. that it is still seasonal, and that the feed was available to be taken as desired, one can further conclude that the amount of protein consumed over a certain period depends wholly on the intensity of production over the same period. Feeding a mash *ad lib.*, as practised by all poultry-keepers, would seem to be a sound system of feeding and is strongly supported by the facts enumerated above.

Influence on average weight of eggs of each group.—Fig. 7, which shows average monthly weight of eggs produced by each group, is typical of the results published hitherto. The eggs produced by a pullet gradually increase in size until a maximum is reached, the peak being followed by a slight decrease in size. The differences are again not clearly evident from the graphs, and recourse must be taken to Table 5.

TABLE 5. *Average Annual Weight of Eggs produced by each Group and the Differences*

Group	*Average annual weight of eggs*	*Difference in average annual weight of eggs*
	gm.	gm.
Group I . .	53·749±1·072	Diff. Groups I and II 0·269±1·493
Group II . .	53·480±1·040	Diff. Groups II and III 0·406±1·408
Group III . .	53·886±0·913	Diff. Groups I and III 0·137±1·384

Column 3 shows no significant difference, in fact not even an approach to significance, between the average weight of eggs of each group. Unlike the difference in numerical production, there is no progressive increase in size of egg with the increased protein-consumption. Group II had a higher protein-intake than Group I, but has a lower average egg-weight, although the difference is not statistically significant. One can thus conclude that with the feeds used in this experiment an increased protein-consumption within the limits shown in Fig. 4 did not increase the mean weight of eggs.

Again, in comparing the average monthly weight of eggs with the

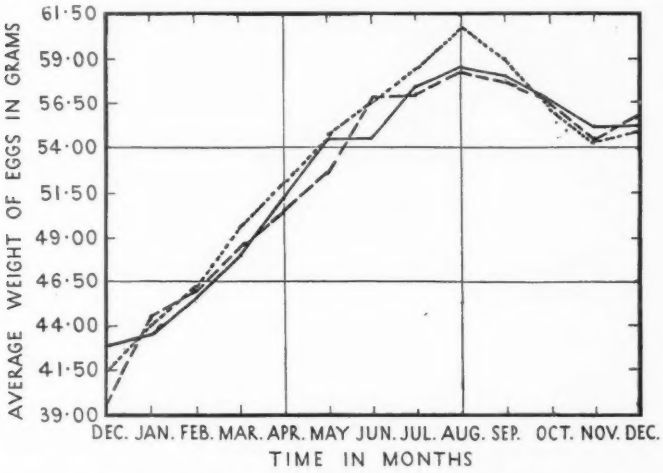

FIG. 7. The average weight of eggs each month of the low-, medium-, and high-protein groups.

monthly protein-intake, it is evident that the weight of the eggs increases independently of the amount of protein ingested. This is quite in contrast with the number of eggs, which shows a close relationship with the protein-consumption. For example, the protein-consumption during March is 47·7 per cent. higher than in May, yet the average weight of eggs laid during May was 10·6 per cent. higher than during March. Further, the average weight of eggs is highest during August, whereas the protein-consumption is the highest two months later, i.e. during October.

There is no correlation between the number of eggs laid during a certain month and the average weight of these eggs during the first year of production. Whilst the average weight of eggs increases in almost a straight line, the numerical production shows violent fluctuations, in fact during May and June there is almost a cessation of laying.

Increase in body-weight.—Fig. 8, showing the average weight of each group during each month obtained from a single weighing each month, is not as accurate as it would have been had weekly weights been averaged

to obtain the monthly weight. Being an average of a number of birds the general tendency can be shown.

No consistent differences are noticeable from the three graphs. Table 6 is therefore included to show the average weight over the experimental period and the difference.

TABLE 6. *Average Weight of Monthly Weighings for Three Groups*

Group	*Average weight of 13 monthly weighings*	*Difference in average weight*
Group I . .	1631·4±24·444	Diff. Groups I and II 26·3±31·27
Group II . .	1657·7±19·759	Diff. Groups II and III 9·4±32·74
Group III . .	1667·1±26·108	Diff. Groups I and III 35·7±35·77

A progressive increase in average weights is evident from Table 8, although no difference even approaches significance.

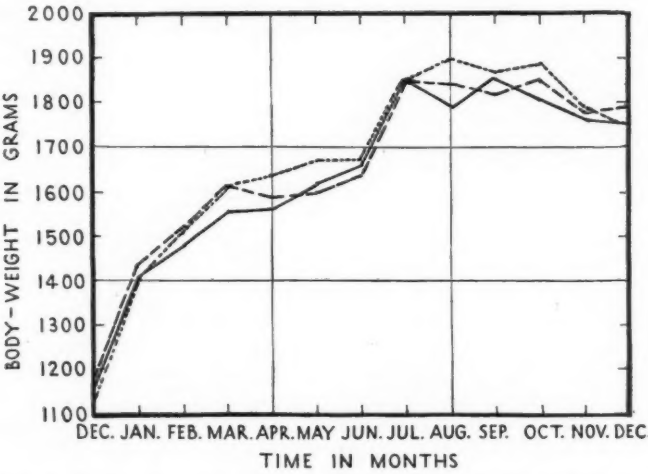

FIG. 8. Increase in average body-weight per bird per month of the low-, medium-, and high-protein groups.

Month for month there is a very close correlation between the average body-weight and the increase in weight of eggs produced (see Figs. 7 and 8), as will be more clearly shown in the second part of this paper. Following the course of these two graphs, they are fairly similar except during the winter months of April, May, and June, when there is only a very small increase in weight. This coincides with the lowest protein-consumption, as shown by Fig. 5.

Conclusions

1. The amount of mash consumed by three groups of pullets when self-fed mash, grain, and separated milk, depended on the protein-content of the mashes and on the season of the year.

2. The consumption of grain was fairly consistent throughout the year, especially when compared with the consumption of mash, which showed violent seasonal fluctuations.

3. Differences in milk-consumption were not consistent, except that the high-protein group consumed very much more than either the low- or the medium-protein group.

4. There was a definite difference in protein-consumption of the three groups. All fluctuated consistently during the various months of the year. There was also a definite difference in the ratio of protein to total carbohydrate of the feed consumed, but the birds showed a definite tendency to balance their rations to a common nutritive ratio.

5. A progressive difference in numerical production of recorded eggs was shown, although the only significant difference occurred between Groups I and III, i.e. groups having consumed the lowest and highest amounts of protein. This does not, however, exclude the possibility that had it been possible to attribute eggs laid outside traps to their correct owners, the difference would remain significant.

6. The various amounts of protein consumed did not cause any difference in egg-size approaching statistical significance. The same applies to differences of body-weight.

7. The numerical production each month in all these groups showed a very close relationship with the protein consumed during that month.

8. There was a very consistent increase in egg-size until August, almost amounting to a straight line when graphically represented. There seemed to be no relationship whatsoever between the amount of protein consumed and the number of eggs produced from month to month and the size of egg produced during corresponding months. The gradual consistent increase of egg-size was quite independent of environment and feeding, but closely related to increase in body-weight during the first year of laying.

REFERENCES

1. H. Atwood, Some Factors affecting the Weight, Composition, and Hatchability of Hen Eggs. W. Virg. Agric. Expt. Stat. Bull. No. 145, 1914.
2. Nils Hansson, Nahrungsbedarf der Eier-legenden Hühner. Z. Tierzüchtg. u. Züchtungsbiol., 1929, **13**, 161.
3. W. R. Graham, Jun., Some Factors affecting the Weight of Egg in Domestic Fowl. Scient. Agric., 1932, **12**, 427–46.
4. M. R. Curtis, Factors influencing the Size, Shape, and Physical Constitution of the Egg of the Domestic Fowl. Maine Agric. Expt. Stat. Bull. No. 288, 1914, pp. 105–36.
5. R. Fangauf and E. Kallmann, Beliebige Aufnahme von Eiweissfutter bei Legehühnern als eiweißsparende Fütterungstechnik. Arch. Geflügelkde., 1933, **7**, 1. (Quoted from a summary.)

6. T. C. BYERLY, H. W. TITUS, and N. R. ELLIS, Production and Hatchability of Eggs as affected by Different Kinds and Quantities of Proteins in the Diet of Laying Hens. J. Agric. Res., 1933, **46**, 1–22.
7. H. L. KEMPSTER, The Influence of Animal and Vegetable Proteins on Egg-production. Missouri Agric. Expt. Stat. Bull. No. 225, 1924.
8. R. T. PARKHURST, Some Factors affecting Egg-weight in the Domestic Fowl. Poultry Sci., 1933, **12**, 97–111.

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RICE-GROWING IN AUSTRALIA

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Introduction.—Although the production of rice in Australia is comparatively small, the industry has been so rapidly established that it has supplied the home requirements of Australia within the short period of six years since its inception. At the present time the production is being stabilized to meet the requirements of the Commonwealth and to allow of a small exportable surplus.

The success of rice culture in the San Joaquin Valley of California, where the soil, climatic, and economic conditions are very similar to those obtaining on the Murrumbidgee Irrigation Area, induced the trial of rice locally, and so successful were the trials that the industry became established immediately.

The growing of rice is very localized, being confined to the Murrumbidgee Irrigation Area in New South Wales. This does not mean to say that this is the only place in Australia suitable for the production of rice. The area on which rice could be grown as well and as cheaply as that at present used, could be very considerably extended. From the point of view of national economy, however, it is considered better to confine the area used for rice production to the present sowings, at any rate, for the time being. Any considerable extension of the area would only lead to an increase in the exportable surplus, which returns a lower price than that sold on the home market. The following table gives the area sown and production since commercial production began:

Season	*Area sown acres*	*Production tons*	*Average yield tons per acre*
1925–6	1,978	1,500	0·76
1926–7	4,772	4,887	1·02
1927–8	12,080	16,483	1·36
1928–9	14,321	23,228	1·62
1929–30	19,939	32,862	1·65
1930–1	19,990	26,084	1·30
1931–2	19,517	23,881	1·22
1932–3	22,787	36,000	1·62
1933–4	20,344	41,123	2·05

Soil and water.—The Murrumbidgee Irrigation Area is situated about 400 miles inland from Sydney and 300 miles from Melbourne, and the irrigation water is supplied by the Murrumbidgee River. The flow of this river is regulated by the Burrinjuck Dam, situated near Yass in the highlands, which has a storage capacity of 771,641 acre-feet.

The regulation of the flow of the Murrumbidgee by the dam is of service to private irrigation-plants, for stock, domestic and navigation purposes, flood-control, and hydro-electric generation, besides ensuring a

plentiful supply of irrigation water for the Murrumbidgee Irrigation scheme in drought years. Water is diverted into the main canal of the Murrumbidgee scheme at the Berembed Weir, about 200 miles downstream from the Burrinjuck Dam. Practically the whole of the Murrumbidgee scheme is gravitational and the cost of the water for rice-growing is 5*s*. per acre-foot which, being very low, has an important bearing on the economics of the rice industry.

The holdings on the area are of two types: horticultural holdings ranging from 20 to 50 acres on the lighter soil types, which are used for orchards and vineyards, and large holdings on heavy flat land, ranging from 200 to 400 acres of irrigable land, which are used for field crops like small grains, rice, grazing, &c. Prior to the cultivation of rice, these large holdings appeared to be difficult economic propositions. Dairying had not proved so successful as had been anticipated, and it was difficult to find remunerative types of crops. The introduction of rice-growing has entirely altered this, and these large holdings are now generally considered profitable enterprises.

Climate.—The climate of the district is of the Mediterranean type. The summer is hot and dry, but occasionally the monsoonal thunderstorms reach as far south as the irrigation area; nevertheless, most of the 16 in. annual rainfall occurs in the winter. The winter is mild, but radiation frosts occur. Being 200 miles from the sea there is a fairly marked diurnal temperature wave. The climate may be gauged by the type of fruits cultivated, such as stone fruit, grapes, and citrus. The rice is therefore grown during the summer months and only one crop is possible per year. It is sown as soon as the soil is warm enough to germinate the seed and all danger of frosts is past, i.e. early in October. To obtain maximum crops, the full length of the growing-season must be utilized, because, if seeding is delayed too long, the crop will not mature before the cold weather of the succeeding winter sets in. Harvesting operations begin early in April.

Cultural operations.—The cultural methods adopted have naturally been influenced by the farming methods evolved on the Australian wheat farms, where large areas are cultivated and where large implements are used. Owing to the economic conditions obtaining, the Australian farmer very early turned his attention to labour-saving machinery and implements, and ever since its inception Australian agriculture has been among the most advanced in the direction of mechanization. Whereas the cultivation of rice requires the expenditure of a very large amount of labour in most countries where it is grown, the labour involved in its cultivation on the Murrumbidgee Irrigation Area compares favourably with that required for wheat-growing. This fact, together with the large areas of heavy flat land and the abundant supply of cheap water, explains why rice can be grown under conditions of European standards of living in competition with that produced in the Orient.

The seed-bed for the rice is prepared by the use of large implements, similar to those used for the cultivation of wheat. Then the land is subdivided into basins by levees or checkbanks, the construction of which is a relatively simple and cheap operation. They are merely ridges

of soil at least 18 in. high, constructed by means of delvers drawn by horses or tractors. Owing to the flatness of the land, large rectangular basins, 3–8 acres in extent, can be used, there being no necessity for constructing the checkbanks on contours, so that the construction of them is not unduly expensive. Little or no grading is necessary, but the land is smoothed. The greatest variation of level of the land within a basin is a few inches only.

The original method adopted in germinating the rice was to flood the bays, drain, and then drill in the seed as soon as the soil was in a fit state. The soil was then kept moist by irrigation, if necessary, until the rice was about 6 in. high, when the flood-water was applied and maintained. This method is quite suitable for the first crop of rice grown on the land, as it is quite free from weeds, but if persisted in every succeeding crop becomes more weedy. The chief weed is barnyard grass (*Echinochloa crus-galli*, several varieties). Cumbungi (*Typha latifolia*), umbrella weed (*Cyperus difformis*), and other weeds that will grow in standing water, are also important.

In order to control weeds, the method of sowing has been modified. A good firm seed-bed is prepared and the seed is sown at a shallow depth in the dry soil. Water is then applied to wet the ground. Two or more waterings may be necessary to induce germination. A good germination of the rice and barnyard grass results. When the rice is just appearing above the ground, the flood-water is run on just sufficiently to cover the barnyard grass; this treatment drowns out the weed, but the rice survives.

When the rice has grown sufficiently, the depth of the flood-water is increased to about 6 in. and maintained at this depth until it is drained off a few weeks before harvesting. As the weather is cool, and the evaporation comparatively low at harvest time, the soil does not dry very quickly. The heavy rice soils are very sticky when wet, and the great problem in harvesting is the management of heavy implements on this sticky soil.

At first, various types of harvesting implements were used, including headers (combine-harvesters) and reaper and binders. It is difficult enough to draw implements over the sticky soil when the work done is only that of moving the implement, but when the driving-wheel of the implement must work the mechanism, the difficulties are very greatly increased. The ingenuity of the farmers and implement-makers has overcome this difficulty, and what is known as the 'rice-header' is now used. This machine is practically an ordinary wheat-header, modified to handle a crop yielding four to five times as much as wheat. It removes the heads of rice from an 8- or 10-ft. strip and threshes the grain, delivering the paddy rice into a bin. The mechanism is driven by an oil-engine, which is part of the implement. The whole is drawn along by either horses or a tractor, so that the wheels of the implement are not impeded by driving the mechanism, and the only pull on the drawbar is that necessary to move the implement along.

In this way the harvesting is completed very quickly. The expeditious removal of the crop is important, as any rains that fall during the harvesting lead to serious delays, making the soil more sticky, and thus increasing the cost of the operation and depreciating the value of the rice.

Crop rotations.—The industry has not been established long enough for any very definite schemes of rotation to have been worked out and adopted. Experience shows that on land growing rice for the first time, quite good crops are obtained with very indifferent soil preparation, so long as the seed is sown at the right time and one attends to such essentials as the correct construction of checkbanks.

It also appears that several good crops could be grown on the same land successively, but for one difficulty; and that is weed-control. Here, as in California, weed-control is the most serious problem of the rice-grower. Rotations and other cultural methods will largely revolve around the solution of this problem.

Under Australian conditions, it is difficult to get the land into a suitable condition to grow a second good rice crop immediately after a crop is harvested, so that the rice crop is often followed by a crop of wheat. After the rice crop is harvested in the autumn, a heavy stubble is left which is not in a fit state to burn until the summer. If it is desired to fallow before the wheat crop, the land is best ploughed the following winter and kept fallow through the summer, and the wheat sown the following autumn. Such a programme is illustrated as follows:

Rice sown October 1930.
Harvested April 1931.
Stubble burnt December 1931.
Ploughed June 1932.
Fallow until wheat sown.
Wheat sown April 1933.
Wheat harvested December 1933.
Rice sown October 1934.

With this scheme only two crops are obtained in the four years, and this is hardly sufficient. It is possible, however, to plough the land as soon as the rice stubble is burnt and have a short fallow, sowing the wheat the following April (1932), that is, a year earlier than in the above rotation. A crop of oats and peas could then be sown in April 1933, grazed off, and the land fallowed from December till the following October, when rice would again be sown. The programme would then be as follows:

Rice sown October 1930.
Harvested April 1931.
Stubble burnt and ploughed December 1931.
Fallow until wheat sown.
Wheat sown April 1932.
Wheat harvested December 1932.
Oats and peas for grazing sown April 1933.
Fallow December 1933 to October 1934.
Rice sown October 1934.

From the standpoint of the wheat crop, it is better to break the fallow in winter, but the difficulty is to do so after rice without losing a year. The aim is to get one crop of rice in four years.

Wheat is considered the crop next in importance to rice, and one advantage of following rice with wheat is that, although the rice soils are heavy and tenacious, they become wetted to a considerable depth by the continuous flooding of the paddy field. This soil moisture is largely available to the deep-rooted wheat plant and, provided superphosphate is added with the wheat seed and the nitrate-content of the soil is satisfactory, excellent wheat crops are grown after rice. The well-worked fallow ensures a high nitrate-level for the wheat crop. It is possible to obtain a second wheat crop and this is often done with advantage. The land can be grazed between the rice harvest and the fallow, so that it is being put to some use during this period.

It was at first thought that the growing of rice would seriously affect the structure of the soil: the heavy traffic on the wet soil during harvesting would inevitably puddle it. However, it has been found that the dense fibrous root-system of the rice in the surface-layer of the soil prevents this action, and, as a result, the growth of rice appears rather to improve the structure of the soil. Rice was found to have 82 per cent. of its root-system in the first 4 in. of soil [1].

Fertilizers.—Rice does not respond to nitrogen on land that is used for rice for the first time, but on land that has previously grown rice the crop responds to sulphate of ammonia. The usual dressing under these conditions is 2 cwt. per acre. More investigation and experience are required to obtain a better understanding of the conditions in which nitrogen is needed and when the supply of available nitrogen is adequate. There is no doubt that the nitrogen question will have a distinct bearing on future developments of soil management and cultural methods on rice farms.

The usual biological and chemical conditions of an agricultural soil are profoundly modified in the submerged rice soil, so that many practices evolved for other plants do not apply to rice. In particular, it is commonly found elsewhere that nitrates are unsuitable as fertilizers for rice. This was shown by Kelly [2] to be due to the conversion of nitrates to nitrites in the submerged rice soil and the harmful accumulation of the nitrites. However, sulphate of ammonia is used much more than nitrate of soda in Australia, owing to its price, so that for this reason alone sulphate of ammonia is the only nitrogen fertilizer used for rice.

Superphosphate does not lead to any increases in rice yields, but it is often mixed with sulphate of ammonia merely to assist mechanically the passage of the latter through the seed-drill. It seems somewhat surprising that rice does not respond to superphosphate on the Murrumbidgee Irrigation Area, as in the southern agricultural areas of Australia it is almost indispensable for the production of all other annual crops.

Varieties.—At the present time, practically all the rice grown is of the variety Coloro or selections of Coloro. Coloro was introduced from California and is a Japanese or short-grained variety. Recent selections of Coloro are later-maturing, but better yielders. With more experience in harvesting and with the machinery now used, early maturity is not so important, as late crops are harvested quite satisfactorily.

Colusa, a mid-season variety, was also grown but was discarded owing to its contamination with red rice. Wateribune was one of the first varieties tried, but proved too late in maturing. It was a particularly heavy yielder, and with the present improved methods of harvesting, it would fulfil a distinct requirement for late harvesting.

Seepage and drainage problems.—The seepage and drainage problems attending rice-growing on the Murrumbidgee Area are relatively small. When the irrigation area was first planned, a system of drainage-channels was designed, as well as a system of supply-canals and channels. Every farm was provided with a supply-outlet on the highest point of the irrigable land and was also connected to a drainage-ditch at the lowest point. The system of supply- and drainage-channels, therefore, finds an analogy in the circulating system of vertebrates. One difficulty that attended the introduction of rice-growing was the handling of large quantities of drainage-water when the rice lands were being drained in autumn, for when the drains were designed it was not anticipated that they would have to handle such large quantities of water. In many sections the drains could adequately cope with the water, but in others difficulties arose. In some cases, moreover, the drains from the rice farms passed through horticultural sections and a danger of seepage arose, owing to the large amounts of water in the drains in the lighter soil of the horticultural sections. Where supply-channels for rice fields passed through horticultural sections, the holding of the water at a high level in the channel continuously throughout the summer also constituted a menace.

Although the rice soils generally contain more salt than the horticultural soils, very little trouble with salt is experienced with them, as the movement of the water through the soil is very slow. It is on the more pervious soils of the horticultural sections that the accumulation of salt constitutes a serious problem. However, if it is attempted to grow rice on light soil, troubles due to seepage and salt are inevitable. For these reasons, the authorities exercise some control over the land that is used for rice-growing. There is some limit placed on the amount of land a settler can put under rice in any season, and rice-growing is only permitted on suitable soil, where the area sown to rice can be drained without menacing other holdings, or overtaxing the drains. Where rice farms adjoin horticultural farms, rice-growing is not permitted within a certain distance of the horticultural farm. This distance is often about five chains, but is dependent on the nature of the soil. In this way seepage from rice-fields into orchards is obviated.

Experiments and investigations.—The New South Wales Department of Agriculture has established a Rice Research Station on the Murrumbidgee Irrigation Area, where such questions as rice-breeding, fertilizers, rotations, and weed-control are being investigated.

The breeding-work consists of cross-breeding and selecting to develop more prolific varieties and to obtain uniform ripening. Attention is also being paid to the testing of long-grained varieties. The long-grained varieties at present available are too late in maturing for local conditions. The problem of the so-called 'sun cracking' is also receiving attention.

To date there is no serious disease problem or insect menace.

Marketing and controlled production.—As the production of rice in Australia is localized in one district in one State, the industry lends itself to organized marketing and the production can be controlled to a large measure. It is, therefore, not surprising that, with the present world vogue of control of production and trade, the commodity rice should be subject to regulation in Australia.

Legislative power exists in New South Wales for the control of marketing within the State of any agricultural commodity, if a poll of the producers of that commodity is in favour of the control. Rice is one of the commodities so controlled. There is a rice-marketing board consisting of five representatives of growers, elected by a poll, and two Government nominees. This board determines all questions relating to marketing and has wide powers. The Australian price is fixed by agreement with the millers and the area sown to rice is largely controlled. The control of the area sown is effected by the co-operation of the Irrigation Commission, a body which need only supply the quantity of water necessary for a certain acreage of rice.

An import duty on rice effectively prevents the importation of foreign rice. The Rice Board does not necessarily take advantage of this duty to increase the price of rice to the Australian consumer. It is claimed that the duty is used only to ensure the sale of home-grown rice, as without it millers could buy foreign instead of local rice, even though the prices were the same. It would be difficult to determine whether this is actually so or not, as overseas prices fluctuate and there are many considerations that complicate the issue. However, it is probable that the price of rice to the Australian consumer is very much the same as it would be if rice were imported duty-free.

In order to have the advantage of the protective duty, the industry has undertaken to supply Australian requirements of rice, and hence a surplus for export must be grown to allow for seasonal fluctuations in yields. The surplus rice is largely exported to New Zealand and the Pacific islands. The price realized for the exported surplus is below the Australian price, so that growers are paid for the rice delivered on the basis of the total pooled receipts.

The fact that the price received for the exported surplus is below the Australian price does not necessarily indicate that the Australian price is above world parity. The cost of shipping and other charges incidental to export are appreciable and these give the Australian product a certain natural protection; but they are a charge on exported rice, so that, disregarding any protective duty, the difference between the price received by the Australian grower for rice sold in Australia and that sold abroad should be twice the cost of shipping.

When the industry was first established a little difficulty was experienced from the deterioration of the paddy rice in store, owing to its excessive moisture-content. For this reason, rice is not accepted by the Rice Marketing Board unless it contains less than 17 per cent. moisture; if it exceeds this amount it must be stacked in the field to dry out. For the same reason the Rice Marketing Board has found it necessary to store the rice where it is grown and not at the seaboard.

Economics of industry.—It may seem strange that rice can be economically grown in countries like Australia and California that enjoy a high standard of living in competition with eastern countries where it is produced by coolie labour. A protective tariff is not the important economic factor concerned, as rice was profitably grown in Australia for a short time before the tariff operated. The fact is that very cheap labour is not always a great advantage. One man with a modern machine can accomplish as much as a large number of coolies with primitive implements.

There are also certain natural advantages enjoyed by the Australian grower. In eastern countries, rice is often the major or only crop grown, and all available land must be used. This fact often necessitates an enormous expenditure of energy in terracing and preparing the land. Water is often lifted by primitive methods that entail a very great expenditure of labour. Rice is frequently grown on the same land continuously and yields consequently fall.

On the Murrumbidgee Irrigation Area, the area available and under cultivation is very much greater than that necessary to produce the crop that it is at present thought economically worth growing, so that rice need only be grown on the same land about one year in four, and heavy crops can therefore be produced. The economic conditions obtaining, therefore, permit big yields being obtained over relatively large areas with a small expenditure of labour, so that the industry is placed on an equal footing with rice-growing in the Orient. The yields obtained, compared with those of other countries, are very high, the average being about 30 cwt. Three tons is regarded as a good yield, but yields of four tons (200 bushels) are not uncommon on land not previously sown to rice.

REFERENCES

1. E. S. West, The Root-distribution of some Agricultural Plants. Journ. C. S. I. R., Australia, 1929, **7**, 87–93.
2. W. P. Kelly, Hawaii Expt. Stat. Bull. No. 24, 1911.

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THE RICE INDUSTRY OF BRITISH GUIANA

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With Plate 17

History.—Rice is not indigenous to British Guiana and appears to have been first introduced, during the occupation by the Dutch, from Carolina early in the eighteenth century. In the early years of the nineteenth century supplies from the United States were stopped, and favourable consideration was thereafter given to the extension of rice cultivation in British Guiana.

In 1901 a shortage of the Indian crop considerably reduced the supply for the local market and prices advanced. During the Great War grain shortage, transport conditions, and high prices provided an abnormal impetus and export figures rose sharply, to be followed by an almost equally rapid decline. After the War, supplies from India to the Caribbean again became regular; prices fell; there was growing dissatisfaction on the export markets with the quality of British Guiana rice and the Colony's exports continued to fluctuate violently from year to year on a downward trend until 1926 when a record low level was reached.

In 1927–8 the Department of Agriculture was reorganized and a vigorous advertising campaign, simultaneously with a Colony-wide distribution scheme of pure-line seed, was inaugurated. New export markets were sought, and the marketing system studied with the object of developing and modelling marketing methods to meet the requirements of the trade. To collect and disseminate information on behalf of the local rice-export trade, the writer, on Government's instructions, undertook a Trade Mission to Canada, in 1929, via the Caribbean colonies, which included Trinidad, Barbados, and the Lesser Antilles.

The rice industry of British Guiana may now be said to be firmly established and occupies the second position among the Colony's industries, sugar being easily first. The value of the export trade alone, even at the existing low prices, is well above the million dollar figure; in addition, the domestic trade is of considerable importance, as rice is a staple article in the local diet. In 1928 a new high level of exports was reached, and in each of the years 1930, 1931, 1932, and 1933 a new record was attained (Fig. 1).

In the development of the industry the East Indian section of the population, comprising over 40 per cent. of the whole, has played an important part. East Indians brought from India the knowledge and tradition of rice-growing, although, as has been indicated above, the earliest introductions of seed appear to have been made from the southern states of North America during the Dutch and French occupations.

Crop Production

The rice commercially cultivated in the Colony is lowland or aquatic in respect of environment. There are, in certain districts, two crops per

year; the autumn crop is the more important, and is sown from April to June. The spring crop, grown only in those districts where the water-supply permits, is sown from November to December. The varieties in general cultivation occupy, normally, about five months from the nursery stage to maturity.

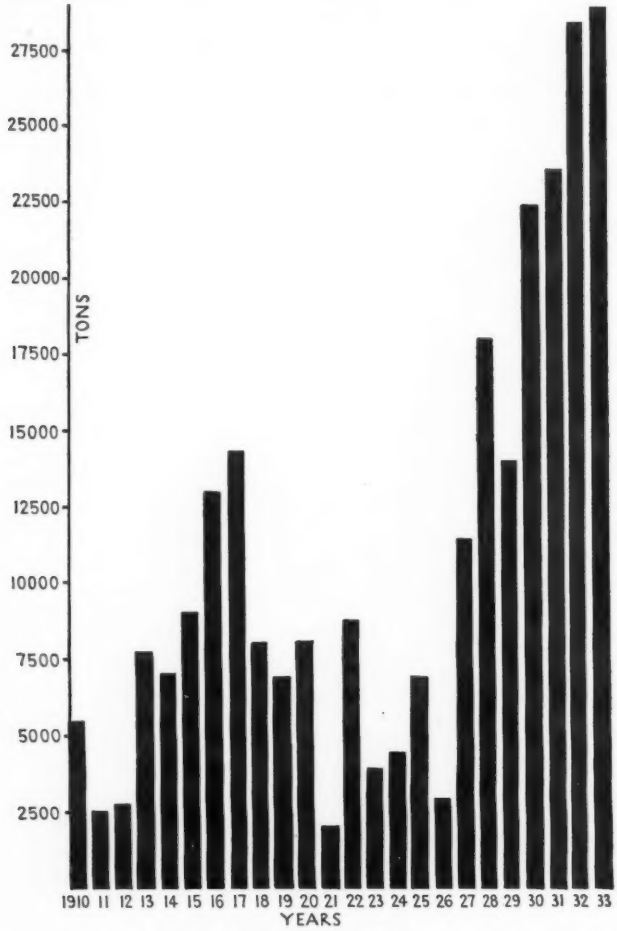

FIG. 1. British Guiana exports of milled rice, 1910–33.

Most of the rice is produced on the coastal belt and along the lower reaches of the several rivers. Before lands in these areas can be agriculturally occupied they must be empoldered[1] and an expensive drainage

[1] The coastal lands are low-lying and natural drainage is, in consequence, difficult. When an area is to be 'taken in', trenches surrounding it are dug on the three landward sides. The earth from these trenches is consolidated into dams which serve as a barrier

and irrigation system laid down. Much of this capital outlay has been provided for the production of sugar, a crop of relatively high financial returns per acre as compared with rice, which has, as a general rule, followed in the wake of sugar. Wherever, for one cause or another, areas have ceased to be cultivated for sugar, they have almost invariably been sown to rice. Further, it has now become the practice for sugar estates to encourage rice-growing on certain cane lands because, *inter alia*, it is accepted that the East Indian labour force is by this means more contentedly and more economically held together. Whilst Government has assisted village areas with drainage and irrigation problems—which are mainly connected with rice and other peasant cultivations—it is nevertheless true that capital invested in drainage and irrigation works by the sugar industry has benefited rice in the past and will continue to do so. There are, unfortunately, still large areas entirely dependent upon seasonal rainfall for rice production, which, under such circumstances, becomes a hazardous business.

A good average yield is 1½ tons of unhulled rice (padi) per acre, obtained when the seed is first sown in nurseries and the seedlings transplanted, whilst in some of the best areas that are growing pure-line seed exclusively, yields of 2 to 2½ tons per acre are not uncommon. Apart from considerations of quality, it has been shown in demonstration plots, in padi competition areas, and wherever careful comparisons can be made, that increased yields, according to conditions, of two to eight bags (140 lb.) per acre are obtained from pure-line seed of strains selected and distributed by the Department of Agriculture.

Table 1 gives some idea of the areas cultivated annually since 1924, together with estimated yields. It should be emphasized that these figures are to a great extent approximations, as there is much difficulty in collecting accurate figures bearing on an industry such as rice under the conditions existing in this Colony. The figures for yields do not necessarily bear a true relation to the area sown since the area actually reaped depends largely on weather conditions—shortage or excess of water. For example, 30 per cent. of the 1933 crop was destroyed by continuous heavy rains. Again, the acreage as given includes all types of cultivation—transplanted, broadcast, and self-sown (volunteer).

The cultural practices are not complicated. Ploughing, as in the East, is usually done by a pair of oxen, the plough being of the simplest type. If necessary there are two ploughings, followed by harrowing, clearance of weeds, and levelling. Levelling is important, because on its thoroughness depends the effective distribution of irrigation-water. Deep tillage is not necessary for rice, and although various types of mechanical implements have been introduced, their use has not become general. The present system is cheap and it persists.

The milling return is approximately 65 per cent. of clean rice to padi, the machinery used being simple and principally of the Engelberg type.

Parboiled rice is the type almost entirely produced in British Guiana,

against the influx of water from surrounding areas. A wall, or dam, is also erected on the fourth side in order to act as a barrier against sea- or, in some cases, river-water. Such an area is then said to be 'empoldered'.

and has obtained its name from the fact that the padi before milling is steeped in hot water, steamed and dried. The advantages claimed for the process are that the husk is more readily removed, the grain is toughened, and can be subjected to severe milling without great loss from breakage, and the parboiled product keeps better and longer than white rice.

TABLE 1. *Production of Padi in and Exports of Rice from British Guiana*

Year	*Padi*		*Rice*	
	Estimated Area	*Estimated Production*	*Estimated Value of Exports*	*Exports (tons) expressed as percentage of 1927 exports*
	Acres	Tons	$	
1924 . .	40,272	42,100	312,587	39
1925 . .	39,890	38,403	523,964	60
1926 . .	49,445	49,899	218,146	25
1927 . .	50,427	59,748	723,871	100
1928 . .	55,560	61,144	1,114,147	157
1929 . .	63,441	72,096	876,407	122
1930 . .	63,482	64,252	1,090,385	195
1931 . .	83,492	78,424	1,060,339	205
1932 . .	87,941	84,783	1,187,871	248
1933 . .	87,125	63,524	1,062,470	253

Research and Extension Work

Pure-Line Development.—An important feature of the work with rice, following the reorganization of the Department, was the inauguration of a programme for the breeding and distribution of pure-line seed to growers throughout the country. Several varieties were collected from the areas under cultivation, but were identified in most cases only by their local names, their precise origin being obscure and pure strains non-existent. In fact, a chaotic condition existed.

It was therefore considered that a pure-line control station, where varieties might be maintained and whence pure seed could be distributed in sufficient quantity, must play an essential part in the expansion of the local industry and the improvement of the product. Careful organization is required in order to keep varieties unmixed in the districts under farm conditions, and even careful growers find that in two or three years padi deteriorates in quality, with red types in the ascendancy.

The purity of strains was established by making single-plant selections grown in 'progeny-row' plots. A regular routine is observed in obtaining pure seed for distribution and is represented in Fig. 2. This, or a similar procedure, is followed in the selection and improvement of many crops by agricultural workers.

This method of producing pure seed on a large scale refers to the selection and distribution of strains of established varieties. When new varieties are found which outyield the standard varieties, they are subjected to carefully conducted trials extending over three or more years.

Data are collected on their milling qualities and on their behaviour in different parts of the Colony before they are finally distributed for extension.

It may be mentioned that the private seed-farms are cultivated by selected growers as far as possible under the supervision of the District Agricultural Officers. To encourage the co-operation of the growers,

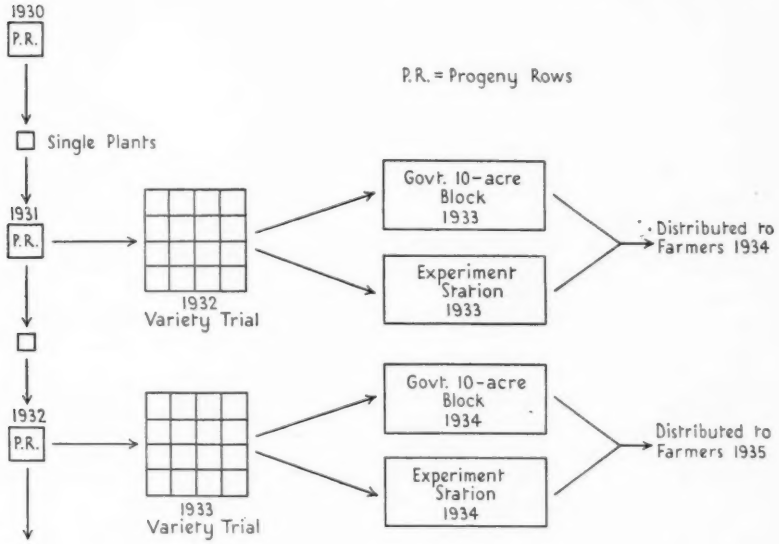

FIG. 2. Diagram indicating method followed for the production and distribution of pure-line seed.

padi competitions are run in the districts and valuable money prizes offered. In addition, the Department obtains the option of purchasing padi of a sufficiently uniform standard at a figure slightly above existing rates. The purchased padi is stored in seed barns centrally located in various rice-growing areas. Certificates signed by the Director of Agriculture are given to those growers who participate in the pure-line padi scheme and whose padi reaches the required standard.

A comprehensive programme of extension work was thus undertaken by the Department of Agriculture through its district staff. The effect was soon apparent; growers became 'pure-seed' minded, the demand for improved seed soon exceeded the supply, and the quality of the rice produced in this Colony was rapidly improved. Five prizes were awarded British Guiana for exhibits of commercial padi at the World's Grain Exhibition held in Regina, Canada, in 1933. The assistance received through the Colonial Development Fund helped generally in the achievements herein recorded, and specifically with the erection of a model rice mill and seed-padi barns, with the provision of the salary for a plant-

breeder, and with the establishment of a revolving fund for the purchase and distribution of seed.

Variety studies.—The policy of the Department is to introduce varieties from other rice-growing countries whenever such varieties appear likely to have qualities suited to local requirements, and a system of exchange with other countries has been adopted. Thus, varieties of the Carolina type are being grown under continued observation with a special view to the production of white rice. Certain other types have shorter growing-periods than the five months occupied by the varieties at present commercially cultivated; this character is being carefully studied, as a good-yielding, early-maturing type is a great desideratum at the present time, especially in areas where two crops are grown annually. Fig. 3 (Plate 17) shows the three padi types most widely cultivated in British Guiana.

Variety trials include studies of yield and other field characters, milling qualities and, in some cases, of cooking and food values. Spacing trials have been undertaken to determine the optimum planting distances in the case of a representative variety and investigations carried out to ascertain the effect of spacing on yield, panicles per clump, length of panicle, and weight of grain per clump. Observations on strength of straw, resistance to pests and disease, viability as affected by age of seed, and the effect of seed-selection by weight and size of grain, are also being made.

The breeding of new varieties is another interesting phase of this work, its principal object being the eventual development of strains which are ideally suited to local climatic conditions and cultural methods and possess suitable milling qualities. This branch of research involves the acclimatization of imported varieties, the creation of new strains by hybridization and subsequent careful selection during several generations from the various divergent progeny produced, the testing in the field of the different strains so evolved, and the evaluation of their respective properties.

The results of a recent yield trial are set out in the following table:

TABLE 2. *Variety Trials conducted by the Department of Agriculture*

Variety	*Demerara*		*Essequibo*		*Berbice*	
	Padi lb. per acre	*Order of Merit*	*Padi lb. per acre*	*Order of Merit*	*Padi lb. per acre*	*Order of Merit*
H 7	3,492	1	3,564	6	3,948	4
No. 79	3,352	2	4,074	1	5,208	1
No. 76	3,114	3	3,640	4	3,906	5
No. 75	3,095	4	3,850	2	3,696	6
Demerara Creole	3,080	5	3,808	3	4,200	3
Blue Stick	2,933	6	3,626	5	4,396	2
A 16·34	2,659	7	3,136	7	3,584	7
C 14·31	2,204	8	3,108	8	3,402	8
Significant Difference (P = 0·05)	227		378		588	

12 replications of each variety. Plots $\frac{1}{80}$ acre each.

Brief notes on some of the more important varieties may be of interest and are given below. In Fig. 4 (Plate 17) the shape and comparative size of the grains may be seen.

Demerara Creole: Good yielding variety; long and somewhat weak straw; apt to lodge when ripe but grains do not 'shatter'; 'Seta Patna' type and slightly curved; percentage of breakage may be high in milling; husk, a light straw colour with tendency to produce awns; anthocyan pigmentation in leaf-sheath, apiculus and stigma; growth-period five months.

H. 7: Identical botanically with *Demerara Creole* and probably derived from it.

Blue Stick: Good yielding variety; does not lodge as much as *Demerara Creole* but grains 'shatter' freely; excellent milling qualities; husk light straw colour; no anthocyan pigmentation; growth-period five months.

No. 75: Grain of the 'Seta Patna' type with a decided curve; husk a dark golden brown colour; anthocyan pigmentation in leaf-sheath, apiculus and stigma; not favoured for general cultivation on account of excessive breakage in milling.

No. 79: A variant of *No. 75*; selected and improved by the Department; grain shorter than *No. 75*; milled rice almost indistinguishable from *Blue Stick* rice; husk golden colour with longitudinal brown furrows; anthocyan pigmentation same as *No. 75*; growth-period five months; proved to be a very successful variety.

Selected and improved strains of *Demerara Creole* and *Blue Stick* varieties are widely grown, whilst *No. 79* is being rapidly extended, already superseding *Demerara Creole* in certain areas. No other varieties are cultivated on a commercial scale.

Manurial and cultural investigations.—It has been determined that applications of fertilizers do not prove profitable on the soils of the experimental areas of this Colony, and it is possible that these soils are still sufficiently rich in the plant-nutrients required by rice to prevent any economic benefits being derived from the fertilizers applied. Nevertheless, a gradual decrease in yields has been noted from the experimental fields of the Georgetown rice station for a number of years and most of the older rice lands in the Colony are now showing evidence of declining yields.

A recent study by the Department of the results of padi manurial trials in other countries as compared with those in British Guiana, has revealed a highly significant correlation (coefficient of $-0{\cdot}9028$) between the yield from the unmanured plots and the yield obtained on manuring (stated as a percentage of the control yield). By the use of a regression equation involving the percentage increase and the common logarithm of the yield (lb. per acre) of the control plot, it seems possible to predict from the given yield of a field the probable increase to be obtained by manuring. Thus, in British Guiana, with the present prices of fertilizers and padi, it would appear not to be a profitable undertaking to manure any area which gives a yield of 2,800 lb. or over per acre. This point has been further elaborated in Rice Bulletin No. 1, 1933, of this Department.

It should be stated, however, that the experimental areas at the disposal of the Department give yields higher than this critical value, but further work is in progress on the whole question.

Trials with various types of implements, simply made to suit local practices, are being continued. Locally, the grain is generally threshed either by hand or by the treading of oxen, the local name for the latter operation being 'bull-mashing'. The Department's trials indicate that threshing-machines are economically justified, and demonstrations in this connexion are being made in the chief rice-growing districts of the Colony.

Control of pests and disease.—The chief field pests of rice are certain stem-borers (*Diatraea saccharalis* F. and *Scirpophaga albinella* Cram.). Although no effective measure of control has been evolved, there are certain agricultural practices, such as the ploughing in of stubble and flooding after reaping, which are found to assist. The Amazon fly (*Metagonistylum minense*) has recently been introduced, especially in connexion with the control of *D. saccharalis* in sugar-cane, and its effect on the control of the same pest in rice is awaited with interest.

The padi bug (*Mormidea poecila* Dall.) punctures the grain with its proboscis and absorbs the liquid contents. Such grains are therefore partly or entirely destroyed. The bug probably does less damage than *Diatraea*, but owing to its seasonal appearance, outbreaks always attract considerable attention. The only important control measures are the destruction of the conspicuous egg-masses and the collection of the adults with hand nets.

The chief pest of the stored product is *Calandra oryzae* L. The systems of padi and rice storage in the Colony do not permit fumigation to be used effectively. Investigations are therefore being made to discover some cheap and practical method for the control of the weevil. To discover such a measure is all the more difficult because the local uniform temperature throughout the year, and the relative humidity varying between 60 and 100 per cent., are so favourable to reproduction by this weevil that seven to twelve life cycles per annum are completed.

It is pleasing to be able to record that rice is little troubled by disease in this Colony.[1]

Trade

The grower usually sells his padi or the milled product to the miller. The miller, in some cases, exports directly, but more usually sells to recognized rice-dealing firms in Georgetown. Such a system, as may be anticipated, led to the shipping of an unstandardized product and to much dissatisfaction on the part of purchasers abroad of British Guiana rice. Government grading, under the direction of the Department of Agriculture, was instituted in 1930. A classification was made in which several grades were specified and defined with regard to colour and breakage, and it became compulsory for all shipments to be Government

[1] For complete details of the results of experiments and other investigations see Administration and Divisional Reports of the Department of Agriculture, British Guiana, 1928–32, and Rice Bulletin No. 1, 1933.

graded. Buyers received greater protection, and increased confidence in the product was established. Later, grading legislation was extended to include blending in order to ensure uniformity in each consignment of a specified grade.

More recently, progress has been made in bringing about co-operation among rice exporters. With this object in view, a Marketing Board was formed in 1932, the chief functions of which were to prevent the commodity from competing with itself on export markets and to promote concerted action in regard to price quotations. This Board's endeavours to bring about price stabilization have met with some success, although numerous difficulties are still being encountered, the chief of which is the practice of giving secret rebates by unscrupulous traders. The ultimate goal must be a centralized, co-operative marketing organization through which all export rice should be handled. To put this plan into operation is fraught with many difficulties at the moment, due to vested interests and financial entanglements extending over a long period of years, involving merchants, millers, landlords, and tenants. Any change must be gradual and must have the support of all parties concerned. A natural corollary is to provide credit through such a central organization for crop production, since the cultivators, under a system of land tenure imposed by the natural conditions on the coastal belt, are obligated in most cases to the landlord-miller, who in turn is dependent on the merchant-financier. A further complication arises in that rice is a food crop, extensively consumed in the Colony; it is subject to frequent price fluctuations dependent on supply and demand, and to severe competition from the cheaply produced Indian product in our natural markets, the neighbouring West Indian Colonies. Any central organization must, therefore, envisage ultimate control of the entire output in order to function efficiently and maintain a satisfactory balance between local consumption and exports. Further, any change from the present system may entail additional charges at present borne by individual merchants and exporters who deal in diversified commodities; these charges are now spread over and allocated to the several articles forming the stock-in-trade of the typical commission dealer to suit his own type of business. In the final analysis due regard must also be paid to the size of the industry, its possibilities of further expansion, and available export markets. The position, which is receiving the most careful consideration of Government, has been explained at some length lest it be thought a simple matter to bring the various interests together by legislative action.

Whilst marketing problems are now largely dealt with by the Marketing Board, the Department of Agriculture has steadily fostered and encouraged production concerning itself with all phases of development and actively participating in all measures calculated to the stabilization of the industry. The Department is co-operating with the Board, of which the Director of Agriculture is a member.

Another step forward has been the passing of legislation for the licensing and better control of the rice mills, especially in regard to building sites, sanitation, weights and measures used, and the keeping of proper records of dealings with rice farmers. It should be noted that rice-

milling in the Colony is carried out by a large number of small mills, of which there are about 200, the practice being for each proprietor of a rice estate to own and operate his own mill, thus enabling him to control his tenants' padi. The practice, though in many respects suited to the conditions existing in the Colony, leads to frequent complaints and dissatisfaction, and militates against centralization.

The research and extension activities broadly outlined in these pages were concurrent with significant development in the industry. An indication of the remarkable expansion which has taken place, in spite of low-price tendencies, may be obtained from Table 1, which gives the estimated production of padi and the exports of rice from 1924, expressed as a percentage of the 1927 exports. (See also Fig. 1.) Unfortunately, a setback (of a temporary nature only it is hoped) is being experienced

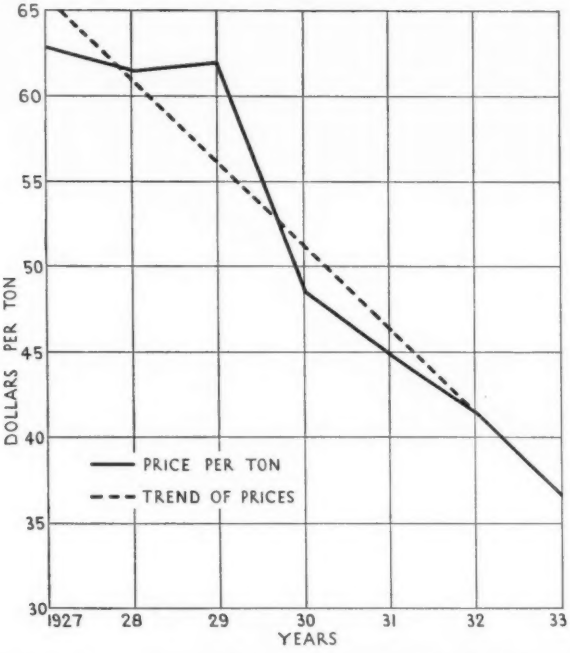

FIG. 5. F.o.b. prices and trend of f.o.b. prices of British Guiana rice, 1927–33.

during 1934 as a result of abnormal weather conditions. Floods that destroyed about 30 per cent. of the 1933 autumn crop (for export in 1934) were followed by drought conditions, which caused a reduction in area of the usual mid-year sowings.

As the rice output increased and the quality of the local product became standardized, new markets were gained. This is indicated by the increase in the number of markets to which British Guiana rice was

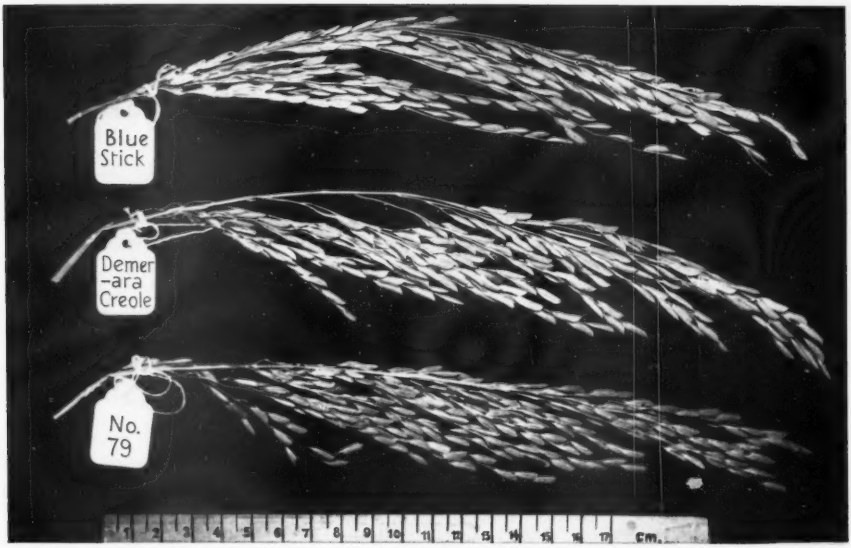

FIG. 3. Showing the three most widely cultivated types of Padi in British Guiana

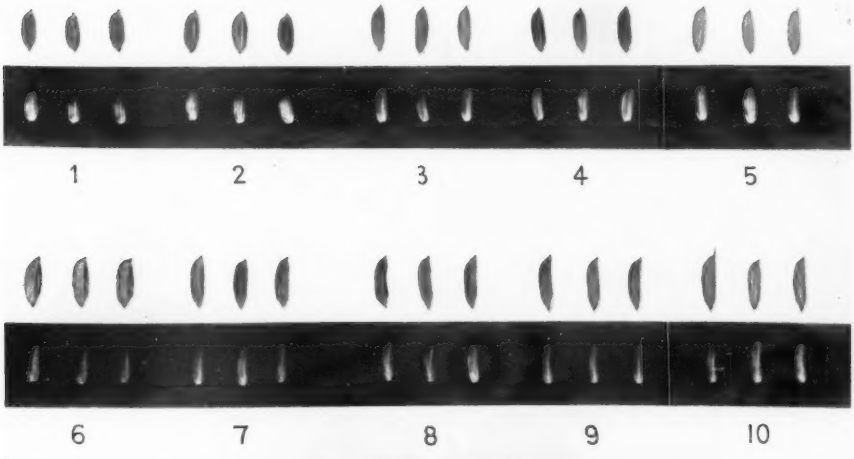

FIG. 4. Showing variation in shape and size of Rice Grains

1. Hope Barley. 2. C 14.31. 3. Blue Stick. 4. No. 79. 5. Ramcajara. 6. Carolina. 7. A 16.34. 8. No. 75. 9. Demerara Creole. 10. Kalyaman

shipped between 1928 and 1933. The bulk of the export trade, however, is with the Caribbean colonies, notably Jamaica, Trinidad, Barbados, and the French West Indies.

The economic conditions that have obtained during recent years in the industry are demonstrated in Fig. 5, from which it is seen that there has been an annual reduction of $4.88 per ton in the f.o.b. price or a decrease of 10 per cent. per year from 1927.

These continually falling prices for the product have reached a point extremely discouraging to the grower, with little sign of improvement in the near future. Indeed, prices have now reached such a low level that any further decrease is likely to react unfavourably on the progress made in recent years, the nature of which has been indicated in this article.

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THE SOILS OF SCOTLAND

Pt. II. THE NORTH-EASTERN REGION

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THE north-eastern region extends from Stonehaven in the south, where the outliers of the Grampian mountains approach the coast, to the Orkney Islands in the north. On the east it is bounded by the sea and it merges gradually into the Highland region on the west. It includes the lower valleys of several rivers which drain the Highland region, together with the plateau of Buchan, the lowlands round the Moray Firth, the plain of Caithness, and the Orkney Islands. In places it is a very narrow shelf (the Highland region extending practically to the sea), but in Aberdeenshire it extends inland in some parts for 30 or 40 miles.

Climate.—The mean annual rainfall over most of the area ranges from 30 to 35 in. (762–889 mm.), but there are places along the Moray Firth where it is as low as 25 in. (635 mm.), and in certain of the more hilly parts it exceeds 35 in. (889 mm.). The distribution of the rainfall throughout the year is fairly even, but generally it is rather greater in the second than in the first six months, and the climate is much less humid than on the west coast.

Geology.—In considering soil formation and soil properties, it is convenient to consider the principal rock types in four main groups:

1. Basic-rock group, including igneous and metamorphic series, e.g. gabbro, norite, diorite, and epidiorite.
2. Acid-rock group, e.g. granite, granitic gneiss, and quartzose schist.
3. Slates and contact-altered schists.
4. Sandstones, conglomerates, marls, and shales of the Old Red Sandstone series. From a soil-forming point of view this is a very heterogeneous group.

Other types are found, but all the above groups occur extensively and cover the bulk of the area. The distribution of these rock types is shown in the geological map accompanying Part I of this paper.[1]

Most of the ground to an altitude of 1,000 ft. (305 m.) is covered with glacial drift of varying depth. This drift in most areas appears to have been influenced profoundly by the underlying rocks and to resemble them mineralogically. In texture it varies from a stiff boulder clay to sands and gravels.

Agriculture and Forestry.—The chief branches of agriculture in this region are the breeding and feeding of cattle and sheep, and the principal crops are rotational grasses, oats, and turnips. There is a considerable area of permanent grass, and other crops grown are potatoes and barley. In the dry sunny region near the Moray Firth some wheat is grown. A common rotation on the cattle-feeding farms is oats, turnips, oats, hay, and two years pasture grass.

Much of the land which is now under cultivation and in a high state of

[1] *Emp. Jour. Expt. Agric.* 1935, **3**, 177.

fertility was formerly covered with thin peat, and usually the laborious reclamation work was done by the small tenant farmers.

Most of the region has extensive woodlands, the area between the Moray Firth and Kincardine being the most densely wooded part of Scotland (17 per cent. of the total area in Nairn). The Scots pine is by far the commonest tree, and about two-thirds of the timber produced is from Scots pine, less than a tenth from hardwoods, and the remainder from larch, spruce, and other conifers. In the west and central regions of Scotland, on the other hand, spruces at present form the main crop species. The commonest hardwood is birch, followed by beech, oak, elm, and ash. The forestry system generally adopted is clear-cutting and replanting, but natural regeneration could be practised. Scots pine, larch, beech, and birch regenerate freely, but with oak and spruce regeneration is not satisfactory. Several exotic conifers, such as Douglas fir, Sitka spruce, and Japanese larch, are now being grown.

Soils.—The following soil groups are found in this region:

1. Podsolic soils.
2. Gley podsolic soils.
3. Gley soils and deep peat.
4. Brown soils.
5. Soils with undeveloped profiles.

Profile descriptions and analyses are given for a range of different parent materials. In the analytical work exchangeable calcium and magnesium were determined by leaching with neutral normal ammonium acetate (after Schollenberger), and exchangeable hydrogen by leaching with normal barium acetate and electrometric titration (after Parker). The results are expressed as m. eq. per 100 gm. soil. The clay fraction analyses were done on material obtained using a time-depth ratio of 8·6 cm./24 hours, with ammonia dispersion.

1 (*a*) *Podsolic soils over granites and granitic gneisses.*—These rocks cover an extensive area in the north-east of Scotland, and the soils which develop on the glacial drift derived from them have been very fully studied at Craibstone, the experimental farm of the North of Scotland College of Agriculture, which is situated 5 miles north-west of Aberdeen.

The composition of the mechanical separates of the surface-layer of a cultivated soil was investigated chemically by Hendrick and Ogg.[1] The conclusion reached was that the soil is composed largely of particles which have not undergone profound chemical weathering, and consists of the original granitic minerals mechanically ground, with only comparatively superficial chemical alteration. Attention was drawn to the large reserves of bases present in the coarser fractions and to the difference between these granitic drift soils and certain south of England soils derived from material which had undergone prolonged chemical weathering prior to the action of the present soil-forming processes. These conclusions were supported by the mineralogical analyses of Hendrick and Newlands,[2] who showed that Craibstone soil has a high content of undecomposed silicates containing large reserves of bases. The fine-

[1] *J. Agric. Sci.*, 1916, **7**, 458. [2] Ibid. 1923, **13**, 1.

sand fraction of a soil from Rothamsted, for example, was found to contain only 5 per cent. of minerals non-quartz, whilst that from Craibstone contained 30 per cent.

The absorption of sulphate of ammonia by Craibstone soil and its various fractions was studied and a comparison with powdered granite was made by Ogg and Hendrick.[1] Later, an examination was made by Hendrick and Newlands[2] of some aspects of the replacement or exchange of bases in the surface cultivated soil by ammonium chloride solution. The relative proportions of exchangeable divalent and monovalent bases found were as follows (per cent.): calcium 85·02, magnesium 8·11, potassium 2·18, and sodium 4·68. Lysimeter studies have been carried out by Hendrick and Welsh on a cultivated soil at Craibstone for the past seventeen years, but this work will be dealt with in a later section of this paper.

Detailed profile studies, including ultimate chemical analyses, were carried out by Stewart[3] on an uncultivated area of gravelly morainic drift, and on a cultivated area of heavier drift. Stewart concluded that the uncultivated soil was an iron humus podsol. He found from mechanical analyses that the carrying down of fine material from the surface into the lower layers had proceeded only to a slight extent, but the chemical examination showed a marked concentration of sesquioxides in the B horizon. The cultivated profile showed little evidence of podsolization, and Stewart suggested that it was at one time podsolized but that cultivation and treatment had brought about a regradation of the profile. The uncultivated profile at Craibstone West Woods may be taken as an example of a podsolized soil on morainic sands and gravels:

Parent material: Sands and gravels, derived mainly from granites and gneisses.

Topography and elevation: Undulating morainic region: 420 ft.(128 m.).

Rainfall and drainage: 34 in. (864 mm.); free.

Vegetation: De-afforestated area, now replanted. *Calluna vulgaris* dominant, *Vaccinium Myrtillus*, and *Erica cinerea*.

(1) 0–2 cm.	Surface litter.
(2) 2–8 cm.	Dark brown to blackish layer with white specks of SiO_2; slightly laminar in structure; plant-remains decipherable and roots abundant.
(3) 8–18 cm.	Sandy loam; light grey mineral particles and brown organic material; structureless; plastic but gritty; plant-remains decipherable and roots present.
(4) 18–30 cm.	Light brown sandy loam; friable and permeable; organic matter well decomposed; roots present; contains scattered vertical intrusions of surface material.
(5) 30–55 cm.	Dark brown, coarse, sandy loam; friable but more compact than (4); organic matter well decomposed; roots stop sharply at bottom of this layer.
(6) 55 cm.+	Yellowish-fawn sand and gravel with horizontal rusty streaks: cemented but quite friable when broken; stones increase in quantity and size with depth.

[1] *J. Agric. Sci.*, 1920, **10**, 333. [2] Ibid. 1926, **16**, 584. [3] Ibid. 1933, **23**, 73.

TABLE 1. *Analyses of Podsolized Soil (over Granite and Granitic Gneiss), Craibstone, Aberdeenshire*

Layer	(2)	(3)	(4)	(5)	(6)
Depth (in cm.)	2–8	8–18	18–30	30–55	55+
pH	5·2	4·5	4·9	5·0	5·8
Loss on ignition %	44·4	12·0	13·8	15·8	4·6
Exchangeable Ca (m. eq.)	13·9	1·5	0·6	1·2	0·4
„ Mg „	4·2	0·8	0·8	0·4	0·3
„ H „	26·3	14·5	14·2	14·2	4·0
Clay %	..	5·7	10·4	5·4	1·5
Clay fraction SiO_2/R_2O_3	..	2·46	1·44	0·91	1·04
„ SiO_2/Fe_2O_3	..	18·42	4·71	3·19	5·39
„ SiO_2/Al_2O_3	..	2·84	2·07	1·28	1·29

The cultivated profile from South Meethill field, Craibstone (adjoining the lysimeters), was developed on a drift of somewhat heavier texture overlying the same type of rock. It has long been under cultivation:

(1) 0–20 cm. Dark grey-brown loam: somewhat plastic, organic matter well decomposed; earthworms present.

(2) 20–45 cm. Yellowish-brown loam with some rusty brown and greyish mottling; variable in thickness and no sharp line of demarcation from layer (3).

(3) 45–125 cm. Brownish boulder clay, with dark grey and blackish mottling due to schistose fragments; becoming more stony with increasing depth.

TABLE 2. *Analyses of a Cultivated Soil (over Granite and Granitic Gneiss), Craibstone, Aberdeenshire*

Layer	(1)	(2)	(3)
Depth (in cm.)	0–20	20–45	45–125
pH	5·6	6·3	6·3
Loss on ignition %	8·8	3·8	3·5
Exchangeable Ca (m. eq.)	6·0	5·2	4·3
„ Mg „	1·2	1·9	2·1
„ H „	10·9	3·4	3·1
Clay %	10·1	13·1	13·6
Clay fraction SiO_2/R_2O_3	2·00	2·09	2·18
„ SiO_2/Fe_2O_3	8·62	8·36	8·09
„ SiO_2/Al_2O_3	2·60	2·90	2·98

From the clay-fraction analyses of these two soils it is evident that the uncultivated profile from West Woods is definitely and fairly strongly podsolized, whilst the cultivated soil from South Meethill field, less than a mile away, resembles a brown soil. Morphologically, however, the cultivated soil shows some evidences of podsolic origin, and it seems probable that its appearance and composition have been altered through cultivation and treatment. It is unlikely that it was ever as strongly podsolized as the lighter-textured West Woods profile.

Many of the cultivated profiles on granitic drift in this region, however, retain the podsol characters both morphologically and chemically. The typical glacial drift, although comparatively light in texture, is often firmly compacted, and in the profile, at a depth of about 40–70 cm. (the depth and thickness of the layer vary a good deal) there is frequently a layer which appears to be cemented as well as compacted. Even when moist it is difficult to dig, and when dry it is almost as hard as a road surface. Portions broken out of this layer crumble readily in the hand, but few roots penetrate into it.

1 (*b*) *Podsolic soils over slate.*—An extensive area of slates occurs in Aberdeenshire, and the soils over this material are usually podsolic or gley podsolic. Much of the land is at a fairly high elevation. Below 1,000 ft. (305 m.) cultivation is common, although considerable areas are under long rotations and used chiefly for grazing; above 1,000 ft. it is rough grazing. In the region studied the glacial drift is often thin.

Two profiles are described[1] from Broom Hill, Wells of Ythan, Aberdeenshire. Both are on glacial drift over slate, at an altitude of 850 ft. (259 m.), and the annual rainfall is about 35 in. (889 mm.). The uncultivated profile is from a thick wood of Scots pine, with occasional beech near the edge.

Uncultivated profile

(1) 0–2 cm. Layer of litter consisting chiefly of pine needles and occasional mosses.

(2) 2–5 cm. Grey, fine, gritty sand; loose, friable, and structureless; many roots.

(3) 5–26 cm. Light grey sandy-loam; fairly compact with tendency to platy structure; patches of loose darker grey material, especially around roots.

(4) 26–28 cm. Compact layer containing hard-pan.

(5) 28–47 cm. Light brown silty loam, with many patches of blackish-brown organic material around roots; ochre spots; roots abundant; pieces of slate present, but less frequent than in layer (3).

(6) 47 cm.+ Light yellow-brown silty sand between shattered slate; hard and compact; occasional roots penetrate.

TABLE 3. *Analyses of a Podsolized Soil (uncultivated), over Slate, Wells of Ythan, Aberdeenshire*

Layer	(2)	(3)	(4)	(5)[1]	(5)[2]	(6)
Depth (in cm.)	2–5	5–26	26–28	28–37	37–47	47+
pH	4·6	4·6	..	4·9	4·8	5·1
Loss on ignition %	..	12·7	11·4	9·5	8·4	3·9
Exchangeable Ca (m. eq.)	13·4	0·9	..	0·9	0·7	0·5
,, Mg ,,	3·7	0·4	..	0·4	0·1	..
,, H ,,	48·3	23·8	..	17·9	17·3	6·4
Clay %	..	14·2	13·5	12·3	13·4	6·3
Clay fraction SiO_2/R_2O_3	..	1·56	0·90	1·10	1·35	1·46
,, SiO_2/Fe_2O_3	..	7·28	2·09	3·16	4·92	6·23
,, SiO_2/Al_2O_3	..	1·98	1·58	1·68	1·85	1·91

[1] Unpublished data supplied by Mr. W. H. Williams.

Cultivated profile

(1) 0–26 cm. Dark grey loam with fragments of slate; fairly compact and roots abundant.

(2) 26–36 cm. Dark yellow-brown silty loam; pieces of slate occur; roots occur but stop at this layer.

(3) 36–49 cm. Similar to layer (2), but contains thin layer of iron pan at about 39 cm.

(4) 49–58 cm. Light yellow, fine, silty loam scattered through shattered slate; very compact.

TABLE 4. *Analyses of a Podsolized Soil (cultivated), over Slate, Wells of Ythan, Aberdeenshire*

Layer	(1)	(2)	(3)	(4)
Depth (in cm.)	0–26	26–36	40–49	>58
pH	5·7	5·7	5·7	5·7
Exchangeable Ca (m. eq.)	4·0	1·7	1·7	2·3
,, Mg ,,	0·6	0·4	0·5	0·3
Clay %	16·0	12·1	21·7	19·5
Clay fraction SiO_2/R_2O_3	2·34	1·76	1·79	1·92
,, SiO_2/Fe_2O_3	16·59	13·20	6·16	8·01
,, SiO_2/Al_2O_3	2·73	2·03	2·52	2·52

Both of the above profiles show marked evidence of podsolization, and from the differences in pH the cultivated soil would appear at some time to have been limed. The cultivated soil has not been profoundly altered, however, as in the case of the cultivated soil at Craibstone.

1 (*c*) *Podsolic soils over the Old Red Sandstone formation.*—The Old Red Sandstone formation occurs extensively in the north-eastern region, and on it is found some of the best agricultural land. As has already been mentioned, this formation provides a wide range of parent materials for soils. Muir has studied several of the soil types, in his survey of the Teindland State Forest.[1] The forest occupies the north-east portion of Findlay's Seat, a hill with an altitude of 860 ft. (262 m.) near Elgin, in Morayshire. He describes three main groups of soils:

1. Normal podsols on fluvio-glacial sands and gravels.
2. Peaty gley podsols with hard-pan on boulder till.
3. Peaty gley soils on boulder till.

The main conclusions reached by Muir regarding the normal podsols at Teindland are as follows:

1. Morphologically, the soils showed evidence of strong podsolization; according to the classification used in Scandinavian countries they would be grouped as iron podsols. The A_1 layer, where present, was never more than a few millimetres thick, and there was a very marked platy structure in the A_2 horizon of two of the profiles examined. The humus-accumulation layer (B_1) was found in all the profiles, but only in one was there any iron pan below this layer.

[1] *Forestry*, 1934, **8**, 25.

2. Mechanical analyses brought out clearly the removal of the clay complex from the upper and its deposition in the lower layers.
3. Clay-fraction analyses showed there had been considerable leaching of both iron and alumina from the upper layers and deposition in the lower layers; alumina, except in one profile, was carried down much farther than the iron.
4. According to the ultimate analyses, most of the main constituents are at a maximum in the lower part of the illuvial horizon, whilst according to the clay analyses, the maxima occur in the upper and middle parts of the illuvial horizon.
5. Except in the organic horizons, the content of exchangeable bases was extremely low, and the pH of the illuvial horizon was generally about 4·5. Further work has shown that there is a marked decrease in the exchange-capacity of the eluvial horizons as compared with the illuvial, probably due to the breaking down of the adsorption-complex.

2. *Gley podsolic soils.*—This would appear to be the commonest type in the areas examined up to the present, and in some localities where it occurs over a comparatively light-textured drift, the gleying seems to be due to the compactness of the drift.

2 (*a*) *Gley podsolic soils over granites and gneisses*
Location: Craigiebuckler, Aberdeen.
Parent material: Boulder clay, derived mainly from granites and gneisses.
Topography and elevation: Gentle slope to flat; 300 ft. (91 m.).
Rainfall and drainage: About 32 in. (813 mm.); slightly impeded.
Vegetation: Cultivated ground.

(1) 0–25 cm. Dark grey-brown crumbly loam; fairly stony.
(2) 25–30 cm. Rusty and humus-stained loam; no structure, stony, occasional soft concretions; roots usually penetrate along humus-stained channels.
(3) 30–50 cm. Brown and grey stony loam; fairly compact; roots penetrate to about 60 cm.
(4) 50–115 cm. Brownish boulder clay; somewhat gritty and sandy; stones frequent; compact.

TABLE 5. *Analyses of Gley Podsolic Soil (over Granites and Granitic Gneisses), Craigiebuckler, Aberdeen*

Layer	(1)	(2)	(3)[1]	(3)[2]	(4)[1]	(4)[2]	(4)[3]
Depth (in cm.)	0–25	25–30	30–40	40–50	60–70	80–90	105–115
pH	5·7	5·8	5·9	5·6	5·5	5·7	5·7
Loss on ignition %	12·9	6·4	3·9	3·3	3·1	2·2	2·2
Exchangeable Ca (m. eq.)	7·2	5·1	2·2	2·3	2·7	2·5	2·7
,, Mg ,,	1·5	1·0	1·0	1·1	3·0	2·7	2·6
,, H ,,	13·0	8·2	5·4	5·5	4·5	2·8	3·4
Clay %	14·3	15·1	15·5	20·0	23·5	13·9	18·3
Clay fraction SiO_2/R_2O_3	1·41	1·28	1·66	1·82	1·99	1·97	1·95
,, SiO_2/Fe_2O_3	7·81	5·71	7·22	7·87	9·04	9·59	10·36
,, SiO_2/Al_2O_3	1·71	1·66	2·15	2·37	2·55	2·49	2·40

This soil has doubtless been considerably modified by cultivation, liming, and manuring, but the podsol characters are still evident. Gleying in this case is comparatively slight.

2 (*b*) *Gley podsolic soil over slate*
Location: Hillhead of Chapelton, Glens of Foudland, Aberdeenshire.
Parent material: Glacial till over slate.
Topography and elevation: Undulating upland; 900 ft. (274 m.).
Rainfall and drainage: 35 in. (889 mm.); fair.
Vegetation: Old pasture; very mossy.

(1) 0–15 cm.	Dark brownish-grey, gritty, stony loam; small crumb structure; roots and worms numerous.
(2) 15–40 cm.	Rusty-brown, gritty, stony loam; colour becomes lighter with increasing depth; structureless; roots and root channels common.
(3) 40–70 cm.	Greyish-fawn, gritty, stony loam, with occasional greenish-grey streaks and slight rusty mottling; roots cluster in greenish spots.
(4) 70–100 cm.	Fawn, gritty, stony loam, with occasional greenish-grey streaks and patches.
(5) 100–150 cm.	Shattered greenish slate with a little fine material; sides of slate fragments generally covered with dark film.
(6) 150 cm.+	Solid slate.

TABLE 6. *Analyses of Gley Podsolic Soil (over Slate), Glens of Foudland, Aberdeenshire*

Layer	(1)	(2)	(3)	(4)
Depth (in cm.)	0–15	15–25	50–60	80–90
pH	5·0	5·2	5·2	5·1
Loss on ignition %	16·4	10·6	6·2	4·0
Exchangeable Ca (m. eq.)	2·3	1·6	0·5	0·5
,, Mg ,,	1·6	0·6	0·7	0·5
,, H ,,	25·2	17·8	2·9	2·5
Clay %	17·9	24·1	22·3	11·1
Clay fraction SiO_2/R_2O_3	1·71	1·30	1·71	1·61
,, SiO_2/Fe_2O_3	10·80	4·62	7·21	6·33
,, SiO_2/Al_2O_3	2·03	1·81	2·24	2·17

Compared with the cultivated soil at Craigiebuckler, this soil shows much more definite podsolization, and there are evidences, e.g. lower pH and exchangeable calcium, that it has been less altered by cultivation and treatment.

2 (*c*) *Gley podsolic soil over Old Red Sandstone formation.*—Muir has studied three peaty gley podsols with hard-pan at Teindland. They occurred on red boulder clay and in every case an extremely hard and almost continuous iron pan was present. According to Muir the formation of this pan has led to an impedance in the drainage of the layers above it, with the result that the eluvial layer is no longer of the usual

grey tint, but tends more to an olive-grey colour. Other points noted were:

1. The clay-content of the eluvial horizon was very low and usually rose definitely on passing into the illuvial horizon.
2. A washing down of humus into the lower layers was noted in one profile.
3. Clay-fraction and ultimate analyses showed that these soils had undergone marked leaching, the leaching being as marked as in the adjoining normal podsols.
4. From the ultimate analysis of one profile it appeared that alumina had been removed only to a slight extent, especially from the lower part of the eluvial horizon. Iron, on the other hand, had been strongly leached and redeposited, mainly in the form of hard-pan; the cementing of the sand grains in the pan was due almost entirely to ferric hydroxide and other iron compounds.
5. The peaty gley podsols like the normal podsols were very acid, and the content of exchangeable bases very low, except in the A_0 horizon.
6. A slight increase in the CaO- and a sharp rise in the MgO-content was noted in the hard-pan layer, and Muir suggests this may be the reason for the precipitation of the iron.
7. In two of the profiles there were two well-defined layers above the hard-pan, and it is suggested that under the conditions associated with water-logging there is a tendency for silica to pass into the colloidal state and be leached out.

3. *Gley soils.*—Gley soils with and without a peat-covering are found throughout the area on the various geological formations. An example, without peat, is taken from near Huntly, Aberdeenshire:

Location: Leys of Drummuies.
Parent material: Boulder clay over slate.
Topography and elevation: Moderate slope; 650 ft. (198 m.).
Rainfall and drainage: About 35 in. (889 mm.); poor.
Vegetation: Pasture.

(1) 0–30 cm.	Brownish-grey loam, drying to light grey: worms and roots common.
(2) 30–50 cm.	Rusty-fawn loam; stony and fairly compact; root-channels common.
(3) 50–170 cm.	Fawn heavy loam with rusty and grey mottling in patches; stony, tough, and compact; water oozing in at 120 cm.

There is no layer of accumulation of sesquioxides, and there is evidence of gleying throughout the profile.

Peaty gley soils over Old Red Sandstone were studied by Muir at Teindland. The depth of peat found was variable, but under this the profiles were characterized by a blue-grey layer, or layers, sometimes mottled with purplish-red boulder clay. In an example from Cushley

TABLE 7. *Analyses of Gley Soil, without Peat-covering, near Huntly, Aberdeenshire*

Layer	(1)	(2)	(3)[1]	(3)[2]	(3)[3]
Depth (in cm.)	0–20	30–40	50–60	90–100	160–170
pH	5·7	5·8	5·8	5·7	6·1
Loss on ignition %	9·7	6·8	4·2	4·1	3·8
Exchangeable Ca (m. eq.)	3·3	1·9	0·9	1·9	2·0
„ Mg „	0·7	0·8	0·7	1·0	1·9
„ H „	10·1	4·6	2·9	2·5	1·0
Clay %	31·2	15·9	16·0	18·6	15·7
Clay fraction SiO_2/R_2O_3	1·54	1·55	1·47	1·92	1·85
„ SiO_2/Fe_2O_3	6·52	7·39	9·43	8·19	8·41
„ SiO_2/Al_2O_3	2·01	1·96	1·75	2·50	2·37

Moss, at Teindland, a definite increase was found in the silt and clay fractions in passing from the gleyed horizon into the unaltered till. Clay-fraction analysis showed a decided chemical leaching in the profile. There was practically no change in the SiO_2/R_2O_3 and SiO_2/Al_2O_3 ratios of the layers, but the SiO_2/Fe_2O_3 ratio fell fairly rapidly. Muir suggests that the iron removed was not deposited in the lower layers, but was washed out of the soil.

In the peaty gley soils both peat and mineral soil layers were very acid, the pH in every case being below 5 and the exchangeable bases very low.

4. *Brown soils.*—It has already been noted that certain cultivated soils in areas where the normal type is definitely podsolized have a more or less uniform brown profile, and show little or no translocation of sesquioxides. These soils may be podsolic types, modified through cultivation.

In some areas, however, the brown-soil type appears to be normal, and this type is probably associated with parent material derived from basic rocks. The area of gabbros lying round Insch, in Aberdeenshire, furnished an example of this. The rock in most places is covered with glacial drift of varying thickness, and from mineralogical examination the drift appears to resemble the underlying rock in composition.

In the profiles examined there were no morphological indications of podsolization, even under old coniferous woods. They appeared to resemble the brown earths described by certain continental workers. Gleying at various depths occurs in many of the profiles, but no subdivision of the group has been attempted at this stage.

Mitchell and Muir have recently been investigating the brown soils of the district, and have supplied the following unpublished results:

Location: Carden Wood, Logie, Pitcaple.
Parent material: Glacial drift over basic igneous rocks (gabbro).
Topography and elevation: Gentle slope; 325 ft. (98 m.).
Rainfall and drainage: About 35 in. (889 mm.); good.
Vegetation: *Pinus sylvestris* and occasional *Picea excelsa*; few mosses.

(1) 0–5 cm. Dark brown cloddy loam; occasional stones; worm- and root-channels common.

(2) 5–18 cm. Medium brown loam with slight rusty tinge towards bottom; many stones, mostly of basic igneous origin.

(3) 18–40 cm. Brown loam with slight rusty staining; occasional greyish spots; many stones; roots penetrate to 40 cm.

(4) 40–110 cm. Brown loam; rusty tinge fading out rapidly; many stones; no roots.

TABLE 8. *Analyses of Brown Soil (uncultivated) over Gabbro, Pitcaple, Aberdeenshire*

Layer	(1)	(2)	(3)	(4)[1]	(4)[2]	(4)[3]
Depth (in cm.)	0–5	5–15	15–28	40–50	60–70	100–110
pH	4·7	4·7	4·9	5·1	6·7	6·5
Loss on ignition %	40·9	24·9	10·3	5·1	4·6	4·1
Exchangeable Ca (m. eq.)	6·5	2·2	1·4	9·2	16·2	15·4
,, Mg ,,	2·1	0·6	0·1	4·3	6·8	6·0
,, H ,,	40·8	33·7	15·2	2·9	2·2	2·2
Clay %	..	19·5	12·6	15·6	20·5	18·2
Clay fraction SiO_2/R_2O_3	1·28	1·19	1·19	1·73	1·93	1·81
,, SiO_2/Fe_2O_3	5·04	5·08	4·95	6·70	5·92	5·90
,, SiO_2/Al_2O_3	1·71	1·55	1·57	2·33	2·86	2·62

Profile on cultivated ground

Location: Cultivated ground adjacent to previous profile.
Parent material: Glacial drift over basic igneous rocks (gabbro).
Topography and elevation: Gentle slope; 325 ft. (98 m.).
Rainfall and drainage: About 35 in. (889 mm.); good.
Vegetation: 15-year-old grass.

(1) 0–25 cm. Medium brown heavy loam; crumbly structure; many roots and stones; worms common.

(2) 25–50 cm. Yellowish-brown medium loam; many stones and roots; no worms observed.

(3) 50–100 cm. Light brown with slight greyish and rusty spotting in places; very compact; roots few and small; many stones.

(4) 100–140 cm. Brown rotten rock; sandy and loose in texture.

It will be observed from the analyses of these two profiles that they bear no relation to the podsolized types already described. There is no translocation of sesquioxides and no morphological evidence of podsolization. It appears to be characteristic of these soils to have a marked rise in pH and exchangeable cations at a depth of about 70 cm. They appear to have much in common with the brown earths described by certain continental workers, but it will be noted that the pH at the surface is low, and that there is considerable leaching of bases from the surface-layers. Similar soils have been described by Robinson in Wales.[1]

[1] *Empire J. Expt. Agric.*, 1934, **2**, 258.

TABLE 9. *Analyses of Brown Soil (cultivated) over Gabbro, Pitcaple, Aberdeenshire*

Layer	(1)	(2)	(3)[1]	(3)[2]	(3)[3]	(4)
Depth (in cm.)	0–25	25–35	50–60	70–85	90–100	130–140
pH	5·1	5·6	5·7	5·7	5·6	5·8
Loss on ignition %	14·9	8·6	4·4	4·8	4·1	2·7
Exchangeable Ca (m. eq.)	6·6	3·4	4·3	14·1	10·4	10·8
,, Mg ,,	0·5	0·3	0·4	4·7	2·7	2·4
,, H ,,	11·9	8·4	2·3	2·6	1·8	1·3
Clay %	20·9	11·2	12·9	14·3	4·8	4·1
Clay fraction SiO_2/R_2O_3	1·19	1·11	1·48	1·74	1·57	1·64
,, SiO_2/Fe_2O_3	4·44	4·64	6·28	6·28	5·97	6·16
,, SiO_2/Al_2O_3	1·63	1·46	1·93	2·41	2·13	2·23

Lysimeter studies.—Under the direction of Hendrick, three lysimeters were erected at Craibstone, near Aberdeen, and by means of these, soil drainage has been studied[1] for the past seventeen years on a soil derived from glacial drift consisting mainly of granites and granitic gneisses. (See p. 251 and Table 2 for description and analyses of soil adjoining the lysimeters.)

The lysimeters were constructed without disturbing the enclosed blocks of soil, and the soil has been cropped according to the usual rotation followed in the district. The most important results are as follows:

1. In the cool, moist climate of Aberdeen more than half the precipitation passes through the soil as drainage.
2. The nitrogen removed from the soil in the drainage water is much less than was expected, and is almost entirely in the form of nitrate. The average amount over a period of eleven years was about 12 lb. per acre per annum, and the amount washed out from the manured lysimeters was no greater than from the unmanured. The amount of nitrogen removed in crops is immensely greater than that removed by drainage.
3. No appreciable amount of phosphoric acid has ever been found in solution in the drainage water of any of the lysimeters.
4. Potash is washed out in similar amount to nitrogen, viz. about 12 lb. per acre per annum, and as in the case of nitrogen, no more is removed from the manured than from the unmanured lysimeter.
5. In addition to potash, large amounts of lime and soda and considerable quantities of magnesia are washed away in solution in the drainage water. In many cases more soda is removed than lime.
6. Carbonates are practically absent in the drainage, but it contains considerable amounts of silicic acid.

Soil fertility estimations.—Most of the soils in the north-eastern region are decidedly acid in reaction, and the pH of the cultivated soils is generally in the neighbourhood of 5·5. The principal crops grown, however, are well suited to soils of moderate acidity, and many of the soils

[1] *Trans. Highland and Agric. Soc. Scotland*, 1921, **33**, 56; 1930, **42**, 1; 1932, **44**, 86; 1934, **46**, 202.

have reserves of lime and potash in the form of silicates, which appear in many cases to obviate the necessity for frequent liming. The results of an investigation carried out a few years ago on 'Certain Acid Soils and Growth of Sugar Beet' have been given by Newlands.[1]

Recently, at the Macaulay Institute, Stewart and Robertson have carried out Mitscherlich tests, field and pot, on a series of soils in the north-east. They have found that the contents of available potash in an average soil amounted to slightly less than 1 cwt. per acre K_2O and the available phosphate to about 1 cwt. per acre P_2O_5, i.e. according to Mitscherlich's relative-yield curves the soils show rather greater deficiencies in phosphoric acid than they do in potash. In addition, Stewart has carried out numerous tests in connexion with advisory work for farmers. The methods normally used in this work are as follows: readily soluble potash is estimated in an 0·5 N acetic-acid extract, and phosphoric acid either in this extract by Prescott's volumetric molybdate method, or colorimetrically in an 0·2 N hydrochloric-acid extract according to a modification of Kirsanov's method.

His results show that in general the lime required to bring the soils to a pH of 6·3 may be anything up to about 3 tons per acre calcium oxide. The figures for phosphoric acid generally range from 2 to 10 mg. P_2O_5 per 100 gm. soil, and common values for the potash-content are from 4–8 mg. K_2O per 100 gm. soil. These tests have been correlated with the Mitscherlich pot- and field-experiments, and the general conclusion reached is that the majority of the soils are deficient in phosphoric acid, and a smaller number are deficient in potash.

[1] *J. Agric. Sci.*, 1928, **18**, 704–12.

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SOME ASPECTS OF THE BLACK COTTON SOILS OF CENTRAL PROVINCES, INDIA

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With Plate 18

BLACK soils are very commonly met with throughout the Central Provinces on different geological formations, such as (1) Deccan trap or basalt, (2) sandstone belonging to the Vindhyan system, and (3) the gneissic rocks. These black soils vary considerably in depth and clay-content, according to their position. Those situated at lower levels are generally deep and heavy and contain about 40 to 50 per cent. of clay. The lime-content of these soils generally varies inversely with the rainfall of the localities in which they are found; for instance, black soils of the western part of the Central Provinces usually contain more calcium carbonate than those of the eastern districts, in which the percentage of calcium carbonate is often as low as 0·01. There are, however, special cases in which certain fields that have been subjected to very heavy leaching show an insufficiency of calcium carbonate, whereas others in the same locality contain a reasonable proportion of it. The type of crops grown on the various black soils of the Central Provinces depends, therefore, on the physical characteristics of the soils and the rainfall. Some typical figures of mechanical and chemical analyses of various types of black soils of these Provinces are given in Table 1, which will substantiate the above-mentioned general observations regarding these soils.

Black Cotton Soils

Soils derived from the weathering of trap rock, in particular, which are black, heavy, and climatologically suited to the growth of cotton, are known as black cotton or *regur* soils. They are very common in the trap area, but occasionally a black-cotton-soil formation occurs on a gneissic rock. These soils may have a depth of 2–3 ft. to even 30–40 ft. Ordinarily the depth of black soils utilized for the growth of cotton does not exceed 10 to 15 ft. The deeper soils are put under wheat and other winter crops. The kind of crops grown on this class of soil depends, apart from its depth, to a large extent on the total amount and distribution of the rainfall. It is thus a very common practice to grow cotton on black soil of 10 to 20 ft. depth in districts with a low annual rainfall, i.e. 15 to 20 in., whereas a similar soil would be put under wheat, gram, or peas in districts with a high rainfall, i.e. 35 to 45 in. The soil does not as a rule show any marked horizons in its profile. Samples of black cotton soil, throughout its profile, were taken from the Agricultural College Farm, Nagpur, and subjected to mechanical and chemical analyses; the results obtained are given in Table 2. A photograph of the profile (Plate 18) shows that there is very little difference between the soil and the subsoil. Owing to the washing down of clay particles from the surface-soil, the subsoil is very sticky, and when cut shows a very shiny

TABLE 1. *Mechanical and Chemical Composition of Black Soils from the Central Province and Berar (samples taken to a depth of 8 inches)*

Locality from which samples were taken	*Normal annual rainfall* (inches)*	*Crops normally grown*	*Kind of underlying rock*	*Percentages in air-dry soil passed through one or two M.M. sieve*										
				Moisture	*Loss on ignition*	*$CaCO_3$*	*Coarse sand*	*Fine sand*	*Silt*	*Fine silt*	*Clay*	*Loss by solution in peroxide, HCl treatment*	*Nitrogen*	*pH*
				†Figures as obtained by the sedimentation method										
Akola district	30·3 in.	Cotton Juar (*sorghum vulgare*)	Deccan trap (Basalt)	7·35	7·00	6·32	2·62	8·53	15·84	19·09	36·92	..	0·038	8·0
,,		,,	,,	9·98	7·47	3·21	0·40	5·46	12·80	18·26	44·35	..	0·033	8·1
Wardha district	41·6 in.	,,	,,	6·64	6·02	4·10	2·38	5·99	13·13	20·03	41·51	..	0·050	8·0
,,		Cotton or wheat	,,	9·80	7·10	0·80	0·10	3·61	11·68	16·04	51·45	..	0·048	8·0
,,		Wheat	,,	11·04	6·43	0·35	0·20	3·03	12·42	15·58	51·00	..	..	8·0
Nagpur district	46·6 in.	Cotton Juar	,,	5·31	4·43	0·97	12·40	7·02	14·44	14·60	41·18	..	0·047	7·70
				Figures as obtained by the revised British official method										
Drug district	48·2 in.	Rice	Rocks belonging to the Cuddapah and Vindhyan systems, mainly composed of much indurated and compacted shales, slates, quartzites, limestones and sand-stones	3·03	..	0·12	10·71	20·31	29·35	..	37·40	0·87	..	6·5 to 6·8
,,		Wheat	,,	6·21	..	0·01	4·65	18·44	27·45	..	43·45	0·67	..	,,

* Figures as given by the Indian meteorological department.

† This does not apply to the last three columns.

TABLE 2. *Mechanical and Chemical Composition of a Profile of Black Cotton Soil from the Central Provinces and Berar*

					* Percentages in air-dry soil													
														Total		Available		
Kind of soil	*Locality*	*Normal annual rainfall (inches)*	*Crops normally grown*	*Kind of underlying rock*	*Moisture*	*Loss on ignition*	$CaCO_3$	*Coarse sand*	*Fine sand*	*Silt*	*Fine silt*	*Clay*	*Loss by solution in peroxide, HCl treatment*	P_2O_5	K_2O	P_2O_5	K_2O	*Nitrogen*
(1) Black cotton, surface-soil to a depth of 8 inches	Nagpur district	46·6	Cotton Juar	Deccan trap (Basalt)	6·08	10·62	0·68	2·41	6·23	12·00	15·30	44·85	2·79	0·079	0·262	0·005	0·006	0·049
(2) Black cotton, subsoil, between 2 ft. and 4 ft. (from 1 above)	,,	,,	..	,,	7·52	11·12	0·80	1·21	4·13	12·15	13·50	49·85	2·55	0·062	0·286	0·003	0·002	0·041
(3) Black cotton, soil, below 4 ft (from 1 above)	,,	,,	..	,,	5·73	9·79	14·40	0·93	4·78	12·45	17·15	36·55	2·81	0·076	0·172	0·002	0·010	0·029

* Figures according to the official method adopted by A.E.A. England, 1925.

surface. Figures of analyses of the subsoil sample also show a higher percentage of clay than that found in the surface-soil. The layer of the semi-weathered rock—which is greyish-white in this particular instance —begins at a depth of about 4 to 4½ ft. from the surface. The lime concretionary bed also begins at about the same depth. Occurrence of such lime concretions is a common feature of black cotton soils, but their exact position in the soil profile depends on the depth of the soil. The downward movement of calcium in black cotton soils can be clearly seen from its increasing percentages from the surface to the lower depths. The extent to which silica is leached from the surface-soil is seen from the figures of fusion analysis of the clay-fractions obtained from the various depths of the soil profile. Clay-fractions used for the purpose of this analysis were obtained according to the method described by Robinson [1]. Results obtained are given in Table 3.

TABLE 3. *Results of Fusion Analyses of Clay-Fractions from Black Cotton Soil*

Depth at which sample was taken	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3 (*molecular*)	SiO_2/R_2O_3 (*molecular*)
9 in. . .	57·76	26·26	15·81	3·73	2·69
Below 2 ft. .	60·40	26·42	16·98	3·88	2·75
Below 4 ft. .	61·40	22·64	16·74	4·60	3·13

Black cotton soils of this Province, as well as those found in other parts of India, generally contain a very low percentage of organic matter. This is due to the soils being subjected to a high temperature throughout the year; during the hot weather the maximum temperature of the soil in many instances rises as high as 120°–130° F. The average annual rainfall is not more than 40 in. and in many places it is only 15 to 20 in., almost all of it falling within 3 to 4 months. These arid climatic conditions (as opposed to those of the chernozem belt) are particularly conducive to the rapid oxidation of organic matter, and, in the absence of any very marked additions of organic matter in the form of organic manures or crop residues from year to year, the soils have become deficient in humic material.

Biological Aspects of Black Cotton Soil

Much interest is being shown in the black soils of India because they resemble in certain respects the chernozems that have been intensively studied by workers on the Continent. The biological aspects of black cotton soil have been investigated by the writer for some time, but the information obtained has not yet been published in full. This information has therefore been put together and is presented here briefly.

Rate of decomposition of organic matter.—The rate of decomposition of carbon in black cotton soil was studied on two different types of green manures [2]. Determinations of carbon dioxide were made daily until the amount produced decreased considerably below that given off on the first day. Results obtained are given in Table 4.

The figures given below clearly indicate that the rate of biological oxidation of organic matter in these soils is very vigorous, and, as mentioned before, that accumulation of organic matter cannot be very striking under the conditions obtaining in these soils.

TABLE 4. *Total Amount of Carbon Dioxide evolved and Percentage of Carbon oxidized from Green Manures in 16 days*

Kind of green manure	*Total carbon added as green manure, in mg. per 100 gm. of soil*	*Total carbon dioxide evolved, in mg. per 100 gm. of soil in 6 days*		*Total carbon oxidized in 6 days* %
		As CO_2	As C	
Sann hemp (*Crotalaria Juncea*)	313·60	367·62	100·2	31·96
Dhaincha (*Sesbania aculeata*) .	318·00	350·90	95·70	30·10

Relation of moisture-content of the soils to biological activity.—The maximum water-holding capacity of the black cotton soils, as determined by Hilgard's method, varies from 60 to 70 per cent., depending upon their clay-content. Experience with light soils shows that the biological activities of these soils are at their best when the moisture-content is about three-eighths of the maximum water-holding capacity. In heavy black cotton soil, however, the biological activities are at their best when the moisture-content is about one-half the maximum water-holding capacity, showing that with heavier soils a higher moisture saturation is necessary for the normal functioning of the beneficial soil organisms. This fact is very clearly seen from Fig. 1, which shows the rate of nitrifying-capacity of fresh samples of black cotton soil, taken at periodic intervals, and containing varying percentages of moisture [3].

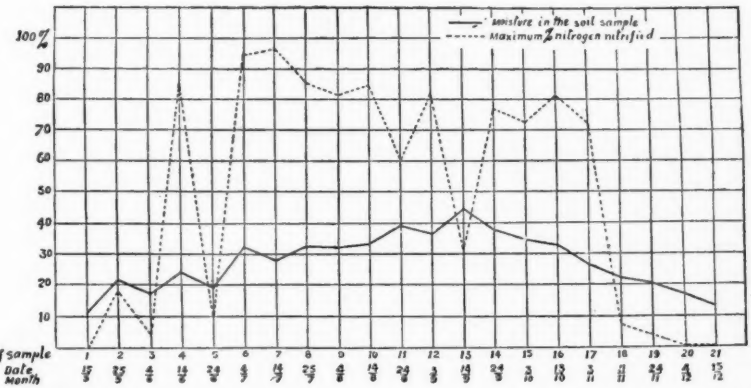

FIG. 1. Variations in the moisture-content of the black cotton soil at different periods and maximum percentage of added nitrogen nitrified in eight weeks. (Maximum water-holding capacity of the soil was 60 per cent.)

Results of nitrification tests with varying percentages of moisture, obtained with air-dry soil samples artificially watered, agree in general very closely with those obtained with soil samples taken direct from the field and shown in Fig. 1. The chief point of difference between the nitrifying capacity of artificially watered air-dry soils and that of moist soils collected from the field was that in the former nitrification appeared to be slow in starting. The total amount of organic nitrogen nitrified at the end of 8 weeks by both types of soils is approximately the same, but soils which have been receiving rain for some time can start their nitrifying action much quicker than air-dry soil brought at once to a 30 per cent. moisture-content. From the observations recorded in Fig. 1, it is further seen that, under natural conditions of climate and rainfall, black cotton soil shows considerable biochemical activity only during four months of the year. A study of the rate of oxidation of organic matter, as measured by the evolution of carbon dioxide, in soil containing varying percentages of moisture, also corroborated the finding mentioned above. Under favourable conditions of moisture the soil can nitrify, very efficiently, organic and mineral nitrogen from various sources. Experiments [4] carried out to study this particular aspect showed that 65–85 per cent. of nitrogen from various types of oil-cakes and green manures added to the soil was nitrified in 8 weeks, and 90 to 95 per cent. of nitrogen added to the soil in the form of ammonium salts or free ammonia was nitrified in a period of 4 weeks only.

The physical condition of the soil also profoundly affects the rate of nitrification. Black cotton soil when moistened with water by hand, for example, assumed a lumpy form very different in texture from that of a soil containing the same amount of water in the field. To determine the effect of the texture of the soil upon its nitrifying power an experiment was carried out in which 30 per cent. of water was allowed to diffuse into the soil without mixing by hand. The results obtained are shown in Table 5.

TABLE 5. *Nitrification of Oil-cake in Black Cotton Soil containing 30 per cent. moisture*

Kind of treatment	*Percentages of added nitrogen nitrified**			
	After 2 weeks	*After 4 weeks*	*After 6 weeks*	*After 8 weeks*
Soil moistened with water by hand .	1·90	43·40	78·85	89·60
Soil moistened by allowing the water to diffuse	18·40	62·90	85·40	93·90

* Nitrified nitrogen includes both nitrite and nitrate nitrogen.

The above details of the nitrifying capacity of black cotton soils indicate that the power of this soil to form ammonia from organic nitrogen from various sources must also be vigorous, and actual experiments carried out to test this particular point have fully substantiated the expectation. In order also to ascertain the individual efficiency of the ammonifying organisms of black cotton soil, nine individual strains of bacteria commonly developing on ordinary agar plates were isolated and purified, but

no attempt was made to identify any of them. These individual strains of bacteria were inoculated into 100 c.c. of Remy's peptone solution, incubated for seven days, and the amount of ammonia formed was determined. It was found that eight out of the nine strains isolated were quite efficient ammonifiers. It was further found that the nitrifying organisms of the soil can tolerate a fairly high concentration of free ammonia and form nitrates from it in the soil [5]. The rate of nitrification with varying concentrations of free ammonia in the soil is given in Table 6.

TABLE 6. *Nitrification of Ammonia in Varying Concentrations*

Milligrams of nitrogen as ammonia, added per 100 grams of soil	*Percentages of added nitrogen nitrified*			
	After 2 weeks	*After 4 weeks*	*After 6 weeks*	*After 8 weeks*
10	80·10	83·00	102·00	102·00
20	70·05	76·75	96·00	96·00
30	74·00	90·00	98·00	98·00
60	34·00	94·00	94·00	92·00
80	5·40	70·00	94·50	94·50
100	3·90	55·10	88·20	92·20
200	Nil	Nil	Nil	6·40
250	Nil	Nil	Nil	0·60

An examination of the figures given above shows that a concentration of ammonia up to 60 mg. nitrogen per 100 gm. of soil, does not materially affect the usual course of nitrification. When the concentration is raised to about 80 or 100 mg. of nitrogen per 100 gm. of soil the nitrifying organisms are affected in the beginning, but they recover from the adverse effects within about a month. Concentrations of over 100 mg. of ammoniacal nitrogen per 100 gm. of soil are very injurious to nitrification. It may, however, be mentioned that under ordinary conditions of manuring and cultivation there is never any possibility of the occurrence in the soil of such high concentrations of ammonia as those employed in the experiment mentioned above.

Summary

1. A brief account is given of the chemical and biochemical aspects of black cotton soil.

2. The lime-content of these soils generally varies inversely with the rainfall of the localities in which they are found.

3. Appreciable amounts of calcium and silica are leached from the surface-soil.

4. A certain amount of clay is also washed down continually from the surface-soil.

5. These soils contain a low percentage of nitrogen and organic matter.

6. The rate of (*a*) biological oxidation of organic matter, and (*b*) formation of ammonia and nitrates from organic nitrogen, in these soils is very vigorous.

7. In these heavy soils the biological activities are at their best when the moisture-content is about half the maximum water-holding capacity.

8. Nitrification in artificially watered soils previously air-dried is slower in starting than with soils receiving natural rainfall, but the nitrifying efficiency after a period of 8 weeks is about the same.

9. A heavy clay soil that has lost its texture shows at first a diminished nitrifying power when compared with the same type of soil in good condition.

10. The nitrifying organisms of the soil can tolerate a fairly high concentration of free ammonia, and form nitrates from it in the soil.

REFERENCES

1. G. W. Robinson, J. Agric. Sci., 1930, **20**, 618–39.
2. D. V. Bal, Agric. J. India, 1922, **17**, 133–51.
3. F. J. Plymen and D. V. Bal, ibid., 1925, **20**, 8–15.
4. —— —— ibid., 1922, **17**, 551–9.
5. D. V. Bal, ibid., 1927, **32**, 298–300.

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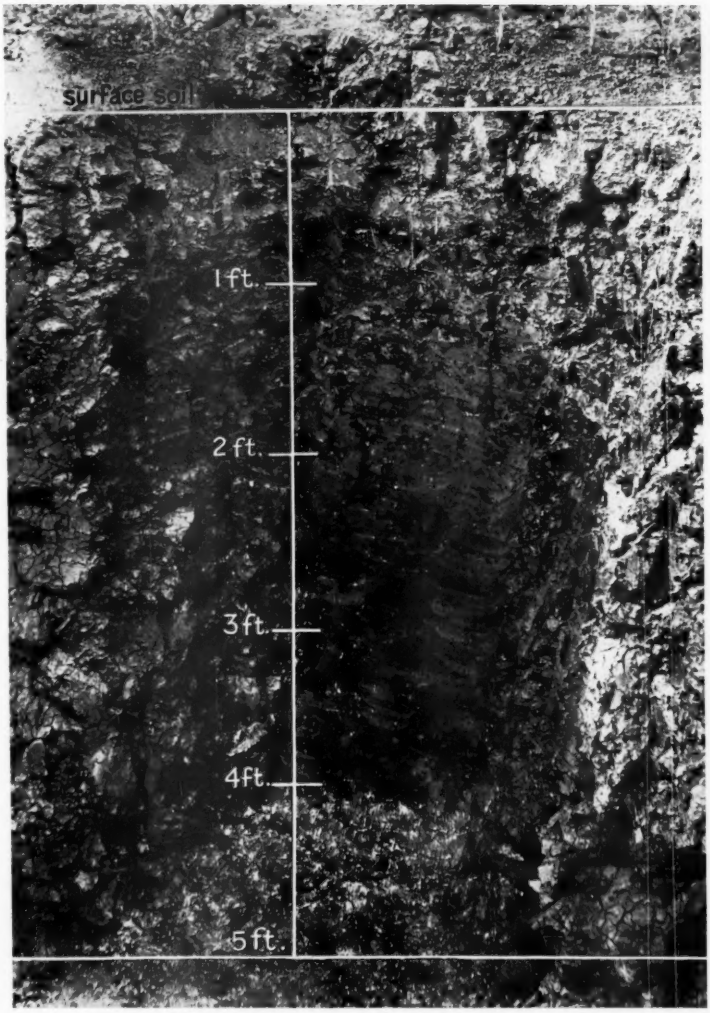

A profile of black cotton soil from the Agricultural College Farm, Nagpur, India

SOILS OF YORKSHIRE

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Natural Features.—By far the largest county in Great Britain, Yorkshire covers an area of about 3,871,000 acres, of which 65·4 per cent. is under crops and grass. In its physical aspect it is constituted of four hilly regions, with large tracts of flat land between them. The Pennine Range, 'the backbone of England', occupies a large area of the county and forms the western boundary. The Yorkshire Pennines are divided into two parts by the Aire Gap; the northern part is mountainous with several peaks above 2,000 ft., the highest being Mickle Fell (2,591 ft.). Nevertheless, this area provides in parts some excellent sheep-grazing of the fescue type, and is sprinkled with very picturesque dales, in which occur alluvial stretches of high fertility. The southern half of the Pennines includes the greater part of the industrial West Riding, one of the most densely populated areas in the country. The higher land (1,000–1,500 ft.) consists of uncultivated grouse moor, covered with heather, *nardus* and *eriophorum*.

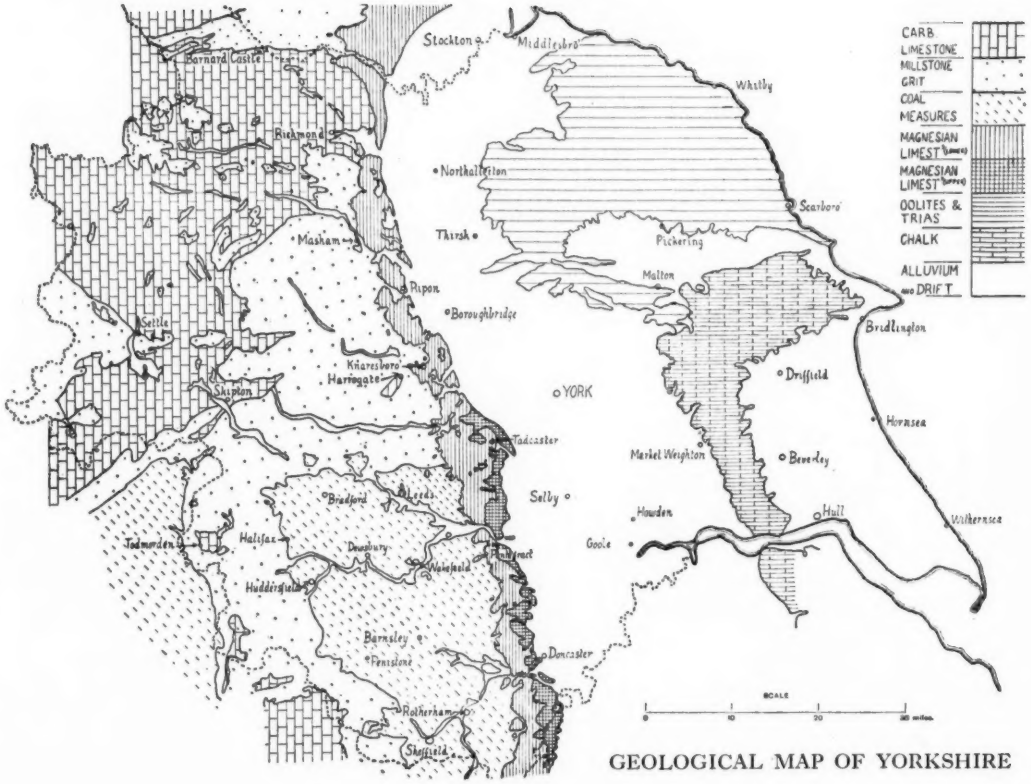
The Cleveland and Howardian hills occupy about 1,000 square miles in the north-eastern part of the county; they are very thinly populated and consist mainly of uncultivated moorland, at altitudes well over 1,000 ft. above sea-level. The Wolds, forming the fourth hilly region, are separated from the Clevelands by the Vale of Pickering, and stretch in a wide band from the North Sea to the Humber, the southern boundary of the county.

From the Pennines on the west and the other hills on the east several rivers converge on to the extensive central plain of the county, known as the Vale of York, and all finally reach the sea at the Humber estuary.

Climate.—The highest mean annual rainfall occurs on the Pennines, where in places it exceeds 60 in., though for altitudes of 800–1,000 ft. it amounts only to 40 or 45 in. At altitudes below 150 ft. it is of the order of 25 in., distributed fairly evenly over the year. The eastern part of the county is drier than the west, but the mean temperature is fairly constant, as is shown by the following data:

Station	*Altitude (ft.)*	*Mean annual rainfall (in.)*	*Mean monthly temperature °F.*	
			max.	*min.*
Meltham (West) . .	514	44·6	53·6	40·2
York	57	24·2	55·2	41·4
Scarborough . . .	158	25·8	53·6	42·5
Hull (East) . . .	18	25·4	53·9	41·9
Harrogate . . .	478	30·6	52·6	40·8

Geology.—The oldest rocks in Yorkshire are the Ingletonian beds, of the Ordovician System, covering a small area in the north-west corner of the county. Rocks of the carboniferous series form the remainder



GEOLOGICAL MAP OF YORKSHIRE

of the western half of the county, limestone in the north, millstone grit in the middle, and coal measures in the south.

Running north and south through the middle of the county there occurs a narrow belt of Permian rocks resting successively on carboniferous limestone, millstone grit, and coal measures. The magnesian limestone of this belt is a rich source of agricultural lime. Lime is also produced from the oolitic limestone which forms the southern boundary of the Jurassic rocks of the Cleveland and Howardian Hills. Jurassic rocks also underlie the chalk in the Wolds of the East Riding.

Throughout Yorkshire there is evidence of glacial action, and the deposits of drift-material attain depths of over 100 ft. in parts of the Vale of York. This drift, in addition to local material, contains stones originating in Scottish and Cumberland rocks. Small outcrops of Trias and Lias appear in this plain. The boulder clay of the Holderness and of the eastern fringes of the Wolds was deposited by the North Sea glacier. The Vale of Pickering in many respects resembles the southern portion of the Vale of York; it is levelled with ancient and modern alluvium, partially covering the boulder clay, and there is evidence that this vale was at one time an inland lake.

Other recent deposits include wind-blown sands, especially in the Vale of York, and there are extensive areas of artificially deposited warp along the banks of the Derwent, Ouse, and Humber.

Soil Types

No systematic survey of Yorkshire soils has as yet been started, but the information available from the intensive study of isolated areas leads to the conclusion that the predominating influence in the formation of soil types in Yorkshire, as in other parts of the country, is the underlying rock or parent material. It is true that in some areas, such as the deciduous forest of Knaresborough, the combined influence of climate and vegetation has obliterated the effect of the parent material to such an extent that some soils derived from millstone grit are almost indistinguishable from some magnesian limestone soils.

Podsols.

In the millstone grits podsol-formation is quite common at altitudes above 700 or 800 ft. Below this level the land is generally cultivated, and in parts is covered with boulder clay, so that any podsols which may have been formed are obscured. Coal-measures sandstone, though much finer in grain than millstone grit, is similar to it in mineralogical composition, but podsols are rare in the coal-measures area, deep layers of peat occurring at the higher altitudes.

Lowland podsols also are found in the eastern half of the Vale of York, iron-pan formation being a feature of some of the 'commons'. Humus podsols are rarer, but a good example is seen in Strensall common. The depth of drift material here is about 60 ft. and consists of a 6-ft. layer of sand overlying stiff boulder clay. Altitude—60 ft., rainfall—25 in.

The description of the sand profile is as follows:

0–6 in.	Peaty sand.
6–14 „	Bleached sand.
14–18 „	Black-humus layer.
18–48 „	Yellow sand.
48–72 „	Reddish sand.

The following are the analytical data:

	0–6 in.	*6–14 in.*	*14–18 in.*	*18–48 in.*	*48–72 in.*
Mechanical Analysis:[1]					
Coarse sand (per cent.)	19·25	25·45	15·30	26·63	29·67
Fine sand (per cent.)	68·70	71·40	71·50	68·46	66·25
Silt (per cent.)	1·30	0·36	0·78	2·10	1·88
Clay (per cent.)	2·70	1·62	4·97	1·10	0·88
Moisture (per cent.)	1·08	0·20	1·59	0·36	0·31
Loss on ignition (per cent.)	9·61	1·42	8·82	1·55	0·90
Other data:					
Fe_2O_3 (sol. in HCl) (per cent.)	0·09	0·17	0·42	0·56	0·94
Al_2O_3 (sol. in HCl) (per cent.)	0·71	0·77	0·61	0·80	0·71
Organic carbon (per cent.)	4·63	0·72	4·25	0·12	0·19
Nitrogen (per cent.)	0·18	0·022	0·17	0·014	0·015
C/N	26·31	32·8	25·01	8·25	12·54
pH	3·36	3·83	3·51	4·34	4·29

The vegetation of this area, once under deciduous forest, consists mainly of heather (*calluna*) and bracken (*pteris*). Each of the four upper horizons, A_0, A_1, B, and C, is clearly marked. There is clear evidence of humus-accumulation in the B horizon; accumulation of the finer mineral particles also is suggested, but sesquioxides appear to be fairly uniformly distributed throughout the profile.

A different type of podsol occurs at Cropton Moor on land belonging to H.M. Forestry Commission. It lies at an altitude of 600 ft. above sea-level and the average rainfall is about 45 in. The parent material consists of a thin sandy drift-layer overlying stiff Oxford clay, the natural vegetation consisting chiefly of heather. A thin iron pan, rich in humus and formed from the upper drift, lies on the surface of the clay, which is extremely acid in reaction.

The layers in the profile are:

0–4 in.	Peat.
4–8 „	Greyish sand.
8–10 „	Reddish-black, indurated layer.
10–16 „	Mottled clay.
16 in. +	Greenish-brown clay.

[1] The mechanical analyses in this investigation were carried out according to the 1928 International Methods; Organic Carbon and Nitrogen, by the method described by Robinson, McLean & Williams (*J. Agric. Sci.*, 1929, **19**, 315).

	0–4 in.	*4–8 in.*	*8–10 in.*	*10–16 in.*	*16 in.+*
Mechanical analysis:					
Coarse sand (per cent.)	..	18·90	16·99	2·92	0·53
Fine sand (per cent.)	..	65·30	59·70	22·73	21·01
Silt (per cent.)	..	6·00	8·85	24·45	32·95
Clay (per cent.)	..	8·20	7·90	42·72	39·05
Moisture (per cent.)	3·68	0·45	1·15	2·62	2·77
Loss on ignition (per cent.)	33·77	4·16	6·15	5·71	5·76
Other data:					
Fe_2O_3 (sol. in HCl) (per cent.)	0·24	0·07	1·56	4·34	4·54
Al_2O_3 (sol. in HCl) (per cent.)	0·38	0·53	1·75	5·90	5·71
Organic carbon (per cent.)	20·82	2·53	2·44	0·60	0·52
Nitrogen (per cent.)	0·86	0·14	0·12	0·11	0·10
C/N	24·27	18·36	19·86	5·68	5·20
pH	3·81	4·08	4·14	4·15	4·15

Post-Glacial Soils.

The Vale of Pickering resembles the Vale of York in the variety of the soil types that are found therein. Alluvium, lacustrine clay, sands, and peat have been superimposed on the boulder clay previously deposited; this clay is, however, exposed in some small areas and forms the soil of the higher lying ground at altitudes between 100 and 130 ft., the general level of the plain being about 80 ft. above sea-level.

Most of the alluvial soils suffer from impeded drainage, and consist of material rich in clay, which in parts is suitable for brick-making. In general this land is under permanent pasture. A typical profile occurs near Kirkby Misperton.

0–12 in.	Dark brown loam.
12–24 ,,	Brown clay.
24–36 ,,	Light brown sandy clay.
36–60 ,,	Blue clay.

	0–12 in.	*12–24 in.*	*24–36 in.*	*36–60 in.*
Mechanical analysis:				
Coarse sand (per cent.)	6·01	3·85	23·24	2·10
Fine sand (per cent.)	27·26	33·46	39·36	4·00
Silt (per cent.)	16·57	23·30	12·23	26·84
Clay (per cent.)	38·25	36·05	21·02	57·68
Moisture (per cent.)	3·25	2·45	1·45	3·15
Loss on ignition (per cent.)	13·26	5·21	3·31	9·70
Other data:				
Organic carbon (per cent.)	6·79	0·67	0·46	1·29
Nitrogen (per cent.)	0·36	0·054	0·059	0·073
C/N	18·81	12·46	7·91	17·63
pH	6·51	6·84	7·34	7·57

The major differences between these various horizons have probably existed since deposition, but the pH figures imply that podsolization may be proceeding.

In all parts of the plain there are large areas of soil known as 'carr'. This consists of a profile normally of two horizons, a peaty soil overlying clay. The water-table is invariably high and often coincides with the junction between the two horizons. The clay horizon is usually alkaline and the peat horizon is only slightly acid. Along the southern boundary of the lake the clay horizon is almost non-existent and is replaced by chalk debris. Such a profile as this occurs at East Heslerton, the description and analytical data being as follows:

0–6 in.	Brown peaty loam.
6–12 „	Black peaty loam.
12–14 „	Greyish sand.
14 in.+	Chalky sand.

	0–6 in.	*6–12 in.*	*12–14 in.*	*14 in.+*
Mechanical Analysis:				
Coarse sand (per cent.)	17·48	22·60	62·38	54·67
Fine sand (per cent.)	4·79	23·11	22·31	28·44
Silt (per cent.)	12·36	8·28	7·47	9·20
Clay (per cent.)	13·85	15·67	4·70	4·50
Moisture (per cent.)	5·26	4·10	0·73	0·56
Loss on ignition (per cent.)	47·96	26·36	3·51	3·27
Other data:				
Organic carbon (per cent.)	25·63	12·54	2·42	0·79
Nitrogen (per cent.)	1·91	1·25	0·14	0·05
C/N	13·44	10·06	17·86	15·01
pH	6·49	5·68	6·18	7·5

Post-glacial sand forms the soil along the edge of the Pickering 'lake'. This band of sand is approximately 500 yards wide, and along the southern edge overlies flinty chalk drift. Such a profile, seen at East Heslerton, shows the following characteristics:

0–9 in.	Greyish brown sand.
9–18 „	Brown sand.
18–22 „	Dark coloured sand.
22–28 „	Brown flinty sand.
28 in.+	White flinty layer.

	0–9 in.	*9–18 in.*	*18–22 in.*	*22–8 in.*	*28 in.+*
Mechanical analysis:					
Coarse sand (per cent.)	59·75	58·82	50·01	53·95	53·62
Fine sand (per cent.)	22·26	27·37	33·95	30·36	30·08
Silt (per cent.)	3·78	1·13	4·06	5·83	10·30
Clay (per cent.)	6·20	4·97	4·72	5·92	3·20
Moisture (per cent.)	1·15	1·08	1·06	0·80	0·37
Loss on ignition (per cent.)	5·08	3·78	3·56	3·48	3·96
Other data:					
Organic carbon (per cent.)	2·57	1·30	0·87	0·80	0·51
Nitrogen (per cent.)	0·33	0·13	0·16	0·07	0·05
C/N	7·84	10·00	5·58	11·00	9·50
pH	7·24	7·35	7·50	7·50	7·50

Most of the soil types occurring in the Pickering district are repeated in the southern half of the Vale of York, which, however, contains some types not found in the former area. The diversity of the soil types in the area south of York is extremely baffling to the cultivator; it is not uncommon to come across the sand type, 'carr', and clay all within the confines of one small field. A particularly interesting clay profile occurs near Wheldrake. It consists of a comparatively thin layer of calcareous boulder clay overlying a layer of sand and gravel, the latter being waterlogged almost throughout the year. This area is situated about 30 miles from the sea, but the altitude is less than 40 ft.

The description of the profile is as follows:

0–8 in.	Dark brown loam.
8–18 „	Brown clay.
18 in.+	Light brown sand.

	0–8 in.	*8–18 in.*	*18 in.+*
Mechanical Analysis:			
Coarse sand (per cent.) . .	3·91	0·95	20·48
Fine sand (per cent.) . .	28·01	2·57	64·07
Silt (per cent.) . . .	36·34	24·88	5·27
Clay (per cent.) . . .	21·58	57·92	8·28
Moisture (per cent.) . .	2·75	3·76	2·66
Loss on ignition (per cent.) .	9·00	9·97	3·47
Other data:			
Organic carbon (per cent.) .	6·64	0·72	0·25
Nitrogen (per cent.) . .	0·57	0·03	0·02
C/N	11·73	28·9	12·48
pH	7·38	7·22	7·44

Such areas as this, although numerous, are comparatively small in extent, and are normally under permanent grass.

(*Received June 1, 1935*)

FURTHER EXPERIMENTS ON THE INTERRELATION OF FACTORS CONTROLLING THE PRODUCTION OF COTTON UNDER IRRIGATION IN THE SUDAN

Pt. I. EXPERIMENTAL

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Introduction.—In a paper [1] published in 1932 the results were given of an experiment, made in 1929–30, comparing the four factors of sowing-date, spacing, amount of irrigation, and nitrogenous manuring, in all combinations, on cotton grown under the Gezira Irrigation Scheme. The experiment was repeated for a second season and confirmed the conclusions based on the first experiment. The application, however, of these conclusions had to be restricted as they referred only to one area. Generalized conclusions for the Irrigation Scheme as a whole could only be obtained by repeating a similar experimental lay-out on areas in different parts of the Scheme within the same season. This communication presents the results of such out-station experiments made in the seasons 1932–3 and 1933–4, and a detailed experiment on the optimum spacing and date of thinning, carried out at Gezira Research Farm, is also included.

Owing to the difficulty of irrigation-control and supervision at out-stations, 'amounts of irrigation' was omitted, and, for similar reasons, the treatment-levels of other factors were also somewhat modified, but the same essential comparisons were retained. The experiments, therefore, comprised only the three factors of sowing-date, spacing, and nitrogenous manuring.

The most striking interrelations of these factors, as demonstrated by the results of the four-factor experiments already published, are:

1. Yield, both with and without nitrogen-application, has an optimal value for August sowing.
2. The returns in yield for nitrogen-application decline with advancing sowing-date (i.e. when cotton is sown successively later).
3. Spacing has little effect with early sowing, irrespective of nitrogen-application.
4. Spacing has a large effect with late sowing, irrespective of nitrogen-application.

OUT-STATION EXPERIMENTS IN THE GEZIRA

The series of out-station experiments outlined in the present paper was undertaken to ascertain how far the above conclusions could be applied to the Gezira Scheme as a whole, and also the extent to which these conclusions might require modifications as a result of local conditions.

The cotton plant is in general very susceptible to damage by disease and pests; and that grown in the Gezira is no exception. Further, owing to the varying rainfall in different areas of the Gezira, the extent of

interference in crop-development due to diseases and pests is very variable even within the same season. It is therefore essential to consider the effects of this interference when interpreting the yield data.

Treatments and lay-out.—The individual treatments compared were as follows:

Sowing-date	*Manure*	*Spacing*
1. *Early*. Aug. 7 .	1. *Control*, no manure	1. *Close*, 30 cm. between holes
2. *Middle*. Aug. 21	2. *Manured*, 100 kg. ammon. sulphate per feddan*	2. *Wide*, 60 cm. between 'holes' (2 plants per 'hole' in both cases; ridges 80 cm. apart)
3. *Late*. Sept. 5 .		

* 1 rotl = 0·99 lb. = 0·45 kg. 1 feddan = 1·038 acres = 0·420 ha. 1 kantar seed-cotton = 315 rotls = 308 lb. = 141 kg.

It should be explained that in the Gezira cotton is sown on ridges, the seed being planted in shallow holes on the tops of the ridges.

The *actual* dates of sowing showed some variation owing to rain, &c., and in the yield table, therefore, these are given for each area separately.

The 12 treatments were replicated in 4 blocks (48 plots) in 1932–3 and in 5 blocks (60 plots) in 1933–4. For convenience in sowing, and to reduce marginal effects, the plots of the same sowing-date were grouped together in each block. Their positions within the block and their subdivisions for the 4 combinations of nitrogen and spacing were assigned at random

The range of sowing-dates and spacings employed in this series of experiments was smaller than in the four-factor experiments of 1929–30 and 1930–1 seasons, as it was desirable to approach more closely to the conditions pertaining to commercial cultivation. Similarly the amount of manure used was only a third of that in the earlier experiments. Consequently it is to be expected that the effects and interactions of the various factors will be less clearly defined.

The ammonium sulphate was applied a week *before* each sowing. This contrasts with the four-factor experiments, where applications were made at 4–6 weeks *after* sowing. The change in method was due to the results of Agricultural Section (Gezira Agric. Research Service) experiments at the Research Farm, which gave optimum responses to fertilizers when applied *before* sowing.

The 1932–3 Season Experiments

Notes on localities.—The sites of the experiments in 1932–3 season, and the distances in kilometres from the Gezira Research Farm (given in brackets), where the earlier experiments were undertaken, were (*a*) Qadd El Ein (66, North), (*b*) Ganneb (57, North), (*c*) Plot 79 Research Farm, and (*d*) Hag Abdullah (49, South). The Chemical Section (Gezira Agric. Research Service) reported as follows on the soils of these areas:

(*a*) *Qadd El Ein*: soil permeable, low salt-content: typical of the more fertile land in the north and west of the Scheme.

(*b*) *Ganneb*: soil permeability very poor, salt-content very high; typical of the poorer land generally.

(*c*) *Gezira Research Farm, Plot 79*: poorer land than the four-factor experiments

of 1929–30 and 1930–1 seasons, permeability rather poor, salt-content high; typical of much of the poorer land of the Central Gezira.

(*d*) *Hag Abdullah*: permeable, but salt-content rather high; characteristic of some of the poorer parts of the Southern Area.

In this season there was no experimental plot in the more northerly areas, nor in the better quality land to the west of the central Gezira area. Otherwise the soil conditions of the experimental plots were fairly typical of large areas of the Scheme.

Rainfall. The records from the rain gauge nearest to each experiment were:

Rainfall (*in mm.*), *1932*

	Qadd El Ein (Toba Gauge)	*Ganneb* (Dolba Gauge)	*G. R. Farm*	*Hag Abdullah*
May . .	..	..	2	15
June . .	49	37	70	91
July . .	50	57	73	102
August . .	133	173	191	309
September .	27	50	35	75
October . .	..*	2	14	..
Total . .	259	319	385	592

* A localized rainfall of about 10 mm. occurred on the station but not at the Toba-Gauge area.

The increase in the rainfall from north to south is characteristic of the Gezira area, and is the main factor determining differences in pest-incidence and physiological development between the northern and southern areas. The rainfall figures also throw light on the distribution of the rainfall before or after the sowings of the various treatments. The totals approximated to the seasonal normal for each area.

Pests

Blackarm (*B. malvacearum*) was general in early and middle sowings of all experiments, but with considerable local variations in intensity. It checked early growth at Hag Abdullah; elsewhere the check was less severe earlier, but persisted and was more severe later, coincident with later rainfall in these areas. At Qadd El Ein the damage from Blackarm was particularly noticeable in late October when the plants were well grown.

There was a sudden attack of Thrips (*Hercothrips sudanensis*) in late October, and it was particularly severe on the late sowings at Ganneb and Hag Abdullah. The infestation was less severe where growth was dense (i.e. with close spacing).

Leaf-curl was general, and a '*Wilt*' caused losses in the late sowings at Ganneb. Further, *White Ants* affected the stand at G.R. Farm and at Hag Abdullah.

The 1933–4 Season Experiments

Notes on localities.—The sites of the experiments in 1933–4 were: Kab El Gidad (93 km. N. of Gezira Research Farm), Umm Degarsi (68 km. N.), Wad Husein (41 km. NW.), Plot 19 Gezira Research Farm, and Hag Abdullah (49 km. S.). No experiment was carried out at Ganneb; Kab El Gidad and Wad Husein were new areas, and that at Umm Degarsi was 2 km. from Qadd El Ein.

The Chemical Section (Gezira Agric. Research Service) reported as follows on the soils of these experimental areas:

1. *Kab El Gidad*: soil slightly inferior to that of Research Farm; found mainly in the northern extension of the irrigated area. Total nitrogen appears to be rather low; average clay-content 50 per cent.
2. *Umm Degarsi*: soil resembles and is superior to that of Research Farm; capillary-rise results for second foot are unusually high; probably more permeable

than most of the Gezira. Total nitrogen appears to be rather low; clay-content 50 per cent.

3. *Wad Husein*: soil resembles but is slightly superior to that of Research Farm; capillary-rise results for second foot unusually high; probably fairly permeable. Total nitrogen apparently normal; average clay-content 50 per cent.
4. *Gezira Research Farm, Plot 19*: soil typical of the Research Farm; much resembles that of the central part of the irrigated area; clay-content 56 per cent.
5. *Hag Abdullah*: soil differs slightly from that of Research Farm in salt-distribution, and also in capillary-rise of subsoil samples, which is low; resembles other plots in Hag Abdullah Block; is superior to soil of the Research Farm. Total nitrogen apparently rather high; clay-content 63 per cent.

Rainfall. The rainfall recorded at the rain-gauge nearest to each experiment, and in no case more than 2 km. distant, was as follows:

Rainfall (in mm.), 1933

	Kab El Gidad	*Umm Degarsi*	*W. Husein*	*G. R. Farm*	*Hag Abdullah*
May . .	9	..	8	31	63
June . .	104	63	81	35	86
July . .	24	67	39	81	114
August .	178	125	106	117	229
September .	11	9	87	52	29
October .	..	7	5	36	13
November .	..	..	1	1	..
Total .	326	271	327	353	534

Pests

Blackarm (*B. malvacearum*) was severe in some areas and light in others. *All* sowings at Wad Husein suffered damage, particularly the earliest. On the remaining areas, Blackarm was general on the first and second sowing-dates; it was more severe at the Research Farm, but slight only at the two northern stations.

Thrips (*Hercothrips sudanensis*) damage was again severe. The second and third sowings at Hag Abdullah were seriously damaged by Thrips infestation, heavy leaf- and bud-shedding resulting in an extensive check in development. Thrips were also general on the second and third sowings at Umm Degarsi and Kab El Gidad, but the damage was only slight.

White Ant damage produced irregular stands at Hag Abdullah and the Research Farm as in the previous season. *Leaf-curl* developed considerably later and was much lighter and of little effect compared with 1932–3 season. *American Boll-worm* (*Heliothis obsoleta*) produced heavy early fruit-shedding in September and October at Wad Husein and to a lesser extent at Umm Degarsi. The damage at Wad Husein permanently affected the crop, the pickings being much later there than elsewhere, owing to the shedding of the early fruits which would otherwise have produced the crop.

In addition to disease-damage at Hag Abdullah a close succession of rain showers in late August, with the associated high humidity, resulted in waterlogging of the crop in *both* seasons. The first and second dates showed leaf-yellowing, and the cotyledons and first leaves were prematurely shed. Stem development was also retarded. When the soil dried out after waterlogging had ceased, the plants returned quickly to normal colour, but were much smaller than usual for their age. In this season the experimental sites were more representative of the whole Gezira area and were fairly typical of the separate areas, with the possible exception of some poorer soils represented by the Ganneb experiment in the previous season.

The rainfall totals per station for this season were similar to those for the previous season, with the exception of the heavy rainfall in late June at Kab El Gidad.

Final Yields of Out-station Experiments

The final yields of seed-cotton for the separate treatments are given in Tables 1 and 2 for the seasons 1932–3 and 1933–4, respectively. The treatment-yields are given in columns under the headings of the separate experiments.

TABLE 1. *Final Yields from Out-station Experiments, 1932–3*

(in kantars per feddan of seed-cotton)

Treatments			Stations				
			Dolga Block				
Sowing	*Spacing*	*Manure*	*Qadd El Ein*	*Ganneb*	*G. R. Farm*	*Hag Abdullah*	*Average all Stations*
August 8–12	30 cm.	No manure	2·60	1·95	1·59	2·26	2·10
	30 ,,	Manured	2·79	2·10	2·34	3·37	2·65
	60 ,,	No manure	2·58	1·75	1·52	1·96	1·95
	60 ,,	Manured	3·11	2·23	2·03	2·28	2·41
	Average		2·77	2·01	1·87	2·47	2·28
August 20–8	30 cm.	No manure	3·05	2·14	2·13	1·50	2·21
	30 ,,	Manured	4·08	2·58	2·58	1·86	2·77
	60 ,,	No manure	2·80	1·73	1·57	0·68	1·70
	60 ,,	Manured	3·49	2·19	2·26	1·28	2·31
	Average		3·36	2·16	2·14	1·33	2·34
Sept. 5 .	30 cm.	No manure	2·96	1·96	1·81	1·45	2·05
	30 ,,	Manured	3·60	2·15	2·63	1·45	2·46
	60 ,,	No manure	2·35	1·34	1·19	0·78	1·42
	60 ,,	Manured	2·56	1·45	1·61	0·91	1·63
	Average		2·87	1·73	1·81	1·15	1·89
	Average all		3·00	1·96	1·94	1·65	2·14

TABLE 2. *Final Yields from Out-station Experiments, 1933–4*

(in kantars per feddan of seed-cotton)

Treatments			Stations					
Sowing	*Spacing*	*Manure*	*K. El Gidad*	*Umm Degarsi*	*Wad Husein*	*Research Farm*	*Hag Abdullah*	*Average all stations*
August 6–11	30 cm.	No manure	3·15	3·49	4·15	2·91	3·57	3·45
	30 ,,	Manured	3·52	3·78	3·86	2·82	3·79	3·56
	60 ,,	No manure	2·56	2·93	3·86	1·98	3·05	2·88
	60 ,,	Manured	3·08	3·16	4·07	2·38	3·78	3·33
	Average		3·08	3·34	3·98	2·37	3·55	3·30
August 20–4	30 cm.	No manure	2·93	3·13	3·80	2·41	1·80	2·81
	30 ,,	Manured	3·23	3·26	4·23	2·55	3·26	3·31
	60 ,,	No manure	2·34	2·56	3·57	2·23	1·43	2·43
	60 ,,	Manured	2·61	2·74	3·93	2·34	2·60	2·84
	Average		2·78	2·93	3·88	2·38	2·27	2·85
Sept. 4–6 .	30 cm.	No manure	2·68	2·92	3·63	2·41	1·88	2·71
	30 ,,	Manured	2·88	2·97	4·10	2·87	2·72	3·11
	60 ,,	No manure	2·18	2·32	2·82	1·61	1·37	2·06
	60 ,,	Manured	2·20	2·28	3·33	2·32	2·13	2·45
	Average		2·49	2·62	3·47	2·30	2·02	2·68
	Average all		2·78	2·96	3·78	2·42	2·62	2·91

The 'significances' of the treatment responses are presented in Table 3. In view of the large variations in yields, due to disease, &c., it is essential to consider the interaction effects in relation to their statistical significance.

TABLE 3. *Summary of the 'significant' Treatment-differences as estimated by the Analysis of Variance*

	1932–3					*1933–4*					
	Q. El Ein	*Ganneb*	*G.R.F. P. 79*	*Hag Abd.*	*Average*	*K. El Gidad*	*Umm Degarsi*	*Wad Husein*	*G.R.F. P. 19*	*Hag Abd.*	*Average*
Sowing date	..	S	S	SS	SS	SS	SS	..	..	SS	SS
Nitrogen	SS	SS	SS	SS	SS	SS	S	S	SS	SS	SS
Spacing	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Sowing and Nitrogen	S	..	..	..	S	S	..	..	..	S	..
Sowing and Spacing	SS	SS	SS	..	SS	..	..	S	..	..	S
Nitrogen and Spacing	..	..	..	..	..	..	..	..	..	..	..
Sowing, Nitrogen, and Spacing	SS	..	..	..	..	..	..	..	..	..	..

Note: 'S' = The experimental z value exceeded the 5 per cent. probability value.
'SS' = The experimental z value exceeded the 1 per cent. probability value.

(1) *Effect of Single Factors*

The effects of the single factors were obtained by averaging the yields of all treatments in which the particular factor is maintained at a particular level, irrespective of the levels of the other factors.

(*a*) *Sowing-date.*—The results for sowing-date are given in Table 4:

TABLE 4. *Yields and Sowing-dates*

(kantars per feddan)

		Sowing I	*Sowing II*	*Sowing III*
1932–3	*Position*	*Aug. 8–12*	*Aug. 20–8*	*Sept. 5*
Qadd El Ein	North	2·77 (100)	3·36 (121)	2·87 (104)
Ganneb	North	2·01 (100)	2·16 (107)	1·73 (86)
Gezira Res. Farm		1·87 (100)	2·14 (114)	1·81 (97)
Hag Abdullah	South	2·47 (100)	1·33 (54)	1·15 (47)
1933–4	*Position*	*Aug. 6–11*	*Aug. 20–4*	*Sept. 4–6*
Kab El Gidad	North	3·08 (100)	2·78 (90)	2·68 (81)
Umm Degarsi	North	3·34 (100)	2·93 (88)	2·62 (78)
Wad Husein	NW.	3·98 (100)	3·88 (98)	3·47 (87)
Gezira Res. Farm		2·57 (100)	2·38 (93)	2·30 (89)
Hag Abdullah	South	3·55 (100)	2·27 (64)	2·02 (57)

The figures in brackets represent the yields of the second and third sowings as percentages of the first sowing, for each experiment. Hag Abdullah in both seasons showed a pronounced optimum at the earliest sowing: the latest sowing actually gave only half the yield of the earliest sowing. In view of the severity of Thrips damage there in both seasons on all except the earliest-sown cotton, it is impossible to decide how much

other factors peculiar to the Hag Abdullah area contributed to this pronounced optimum yield from early sowings.

Although in some cases yields due to different sowing-dates did not differ significantly, it will be seen that all the areas, excepting Hag Abdullah, show a similar trend within the same season. Between seasons, however, the optimal sowing-date shows considerable variation. Thus the second sowing was optimal in 1932–3 and the first optimal in 1933–4 season. This superiority of the first sowing in the latter season was more marked in the two northern experiments than elsewhere. Apart from this, the sowing-date differences at the Research Farm appear to give a reliable indication of the optimum for the remainder of the Gezira Scheme in the same season.

The four-factor experiments of 1929–30 and 1930–1 seasons included only one sowing in August. So far as comparisons can be made, the present series of experiments confirms that the optimum date of sowing is in August, but indicates that a more exact definition of the optimum must include consideration of the particular seasonal characteristics. This aspect is discussed later.

(*b*) *Spacing*.—The results for the spacing comparisons are included with those for manuring in Table 5 (*a*).

TABLE 5. *Yields for Comparisons of* (*a*) *Spacing and* (*b*) *Manuring*

(kantars per feddan)

	(*a*) *Spacing*			(*b*) *Manuring*		
Experiment	*Close*	*Wide*	*Increase with close*	*Nil*	*Ammon. sulph.*	*Increase with ammon. sulph.*
1932–3						
Qadd El Ein (N.)	3·18	2·82	0·36	2·72	3·27	0·55
Ganneb (N.) .	2·15	1·78	0·37	1·81	2·12	0·31
Research Farm .	2·18	1·70	0·48	1·64	2·24	0·60
Hag Abdullah (S.)	1·98	1·32	0·66	1·44	1·86	0·42
1933–4						
Kab El Gidad (N.)	3·06	2·50	0·56	2·64	2·92	0·28
Umm Degarsi (N.)	3·26	2·66	0·60	2·89	3·03	0·14
Wad Husein (NW.)	2·66	2·17	0·49	2·26	2·58	0·32
Research Farm .	3·96	3·59	0·37	3·64	3·92	0·28
Hag Abdullah (S.)	2·84	2·39	0·45	2·18	3·05	0·87

The results in all experiments illustrate the superiority of close spacing over wide spacing, when comparing the yields obtained by averaging the remaining treatments. This agrees with the results of the four-factor experiments, in which, with a still closer spacing (25 cm. between holes), the closest spacing employed was the optimum.

(*c*) *Nitrogen-response*.—The responses to applications of ammonium sulphate are shown in Table 5 (*b*). In all the experiments the manure gave increases in yield, when comparing the averages of other treatments. The Hag Abdullah response is abnormally great in 1933–4, but, otherwise, the yield data do not indicate any general geographic trend over the

Gezira Scheme in the degree of manurial response and, therefore, of soil-nitrogen supply.

Nevertheless the developmental data do indicate a variation in nitrogen response, and presumably, therefore, had disease-damage been negligible, a similar variation would have been demonstrated in the final yields. It is impossible to attach much importance to the abnormally great response to manuring at Hag Abdullah in view of the interference of local factors whose effects have not yet been precisely defined, viz. severe thrips-infestation, and extensive waterlogging of the soil in late August by heavy rainfall.

(2) *The Interactions of the Factors*

Owing to the large error in measuring interaction-effects as compared with errors for single factors, the yields of the separate stations have been totalled to give the average interaction-effects.

(*a*) *Sowing-date and nitrogenous manuring*.—The following table shows the mean interaction-effects over all the experiments for sowing-date and nitrogen-comparisons:

TABLE 6. *Yields for Sowing-date and Nitrogen*

(kantars per feddan)

	1932–3			*1933–4*		
	Sow. I	*Sow. II*	*Sow. III*	*Sow. I*	*Sow. II*	*Sow. III*
Nil . . .	2·03	1·96	1·74	3·16	2·62	2·38
Manured . .	2·53	2·54	2·05	3·44	3·07	2·78
Increase . .	0·50	0·58	0·31	0·28	0·45	0·40

The four-factor results showed that the response to manure was greatest with early sowings and progressively decreased with delay in sowing-date. The results of the 1932–3 season showed smaller responses for September sowings than for August sowings, but the optimum response actually occurred with the later August sowing. In the 1933–4 season the response to manuring was least with the earlier sowing. Thus the partial confirmation of the four-factor results obtained in the first season was not borne out in the second season, but no exact comparison can be made, as the dates of application of manure were different, i.e. some weeks *after* sowing in the four-factor experiments, and *before* sowing in out-station experiments. (The possible effects of these differences are discussed later.) The significant interaction, shown in Table 3, for Qadd El Ein in the 1932–3 season is of the same type as shown in the average of all stations given above. In 1933–4 the two northern stations, Kab El Gidad and Umm Degarsi, on the other hand, showed interactions of the 'four-factor' type, the response being greatest for the earliest sowing and least for the latest sowing: only the former was statistically significant. The Hag Abdullah results showed a more pronounced interaction between nitrogenous manuring and sowing-date than elsewhere,

the superiority of the response at the second date over that at the first date being particularly marked. The average interaction-effects of the 1933–4 season, shown in Table 6, are to a large extent determined by the very marked effects at Hag Abdullah. In the only areas where disease-damage was light, i.e. in the north of the experimental areas, the interaction is of the form established in the four-factor experiments. Hence it is concluded that there are indications of a general interaction-effect throughout the Scheme of a type similar to that obtained in the four-factor experiments, but that differential disease and pest-damage in the different sowing-dates may alter considerably the nature of the interaction.

(*b*) *Sowing-date and spacing.*—The average interaction-effect over the series of experiments in each season for sowing-date and spacing-comparisons are as follows:

TABLE 7. *Yields for Sowing-date and Spacing*

(kantars per feddan)

	Season 1932–3			*Season 1933–4*		
	Sow. I	*Sow. II*	*Sow. III*	*Sow. I*	*Sow. II*	*Sow. III*
Close . .	2·38	2·49	2·26	3·50	3·06	2·91
Wide . . .	2·18	2·01	1·53	3·10	2·63	2·25
Difference . .	0·20	0·48	0·75	0·40	0·43	0·66

Both seasons showed a superiority of close spacing at all dates of sowing, and this superiority increased with successively later sowings. The interaction was less pronounced in 1933–4 owing to the marked increase in yield following close spacing with even the earliest sowings. The significant interactions shown in Table 3 are all of the type indicated by the general averages above. The interaction at Qadd El Ein was particularly marked, as the yield of the earliest sowing with the *wide* spacing was greater than that with the close spacing.

Thus the increased response to closer spacing with delayed sowing-date established in the four-factor experiments for the Gezira Research Farm was confirmed in all experiments in both seasons, and may therefore be regarded as finally established for the whole area at present under irrigation.

(*c*) *Interactions between sowing-date, nitrogenous manuring, and spacing.*—As shown in Table 3, the Qadd El Ein Experiment in 1932–3 showed a significant second-order interaction between the factors, but, owing to lack of confirmation from other experiments, little importance can be attached to this result. Examination of the individual treatment-yields shows that this interaction results from a manurial response, which is greater with *wider* spacing for early-sown cotton, and with *closer* spacing for middle and later-sown cotton. It may be due to Blackarm damage, which was extensive on the early-sown cotton at Qadd El Ein, and has been shown to be more severe on closer-spaced plants [2].

The Spacing, Date-of-thinning, and Date-of-sowing Experiment, G.R. Farm (P. 34–5), 1932–3

Additional information on the importance of changes in optimum spacing in relation to sowing-date is available from a large-scale experiment carried out on the Gezira Research Farm in the 1932–3 season. This experiment also included 'date of thinning' the plants as one of the factors, since it is clear that a change in this date may change the optimum spacing.

Treatments and lay-out.—The 10 spacing treatments comprised comparisons of 1, 2, 4, 6, 8, and 16 plants per metre ridge, with different combinations of numbers of plants per hole. These spacings were repeated at two sowing-dates (Aug. 12 and Sept. 2), and at each spacing thinnings at 3 or 6 or 9 weeks after sowings were compared. Thus each plot was thinned in one operation from about 10 plants per hole (usual after normal field-germination) to 1, 2, or 4 plants per hole, according to the particular treatment. The 60 treatments were replicated four times, in four randomized blocks, making a total of 240 plots on an area of 10 feddans.

For convenience in cultivation and to obtain the largest numbers of replications for the comparisons which were expected to produce the smallest differences, i.e. dates of thinning, the treatments were arranged so that within each block (1) the plots of one sowing-date were grouped together, (2) the 10 spacing-treatments were scattered at random within each group of sowing-date plots, and (3) each unit for spacing-comparisons was subdivided into three to comprise the three dates of thinning-treatments, assigned at random. Thus the effective replication for the single-factor comparisons was: eightyfold for dates of thinning, eightfold for spacing, and fourfold for dates of sowing.

The following is a summary of the statistical analysis of the results:

	'Z' Value			
	Experimental	*5 per cent.*	*1 per cent.*	
1. Sowing date	0·73	1·16	..	Not Sign.
2. Spacing	1·86	0·37	0·52	Highly Sign.
3. Date of thinning . . .	1·52	0·55	0·76	,, ,,
4. Sowing-date and spacing . .	0·85	0·37	0·52	,, ,,
5. Sowing-date and date of thinning	0·92	0·55	0·76	,, ,,
6. Spacing and date of thinning .	0·71	0·24	0·34	,, ,,
7. Sowing-date and spacing and date of thinning . . .	0·02	0·25	..	Not Sign.

All the single factors and first-order interaction-effects are highly significant except that of sowing-date.

The general level was well above the average for the Research Farm and the crop fortunately escaped serious pest-damage, other than by Thrips infestation. The latter caused extensive leaf-shedding in the wider-spaced plants of the later sowing in November, and therefore part of the increased yield with closer spacings must be attributed to relatively less Thrips damage. There was, in addition, a differential effect

of Thrips on the thinning-dates of the late sowing, the latest thinning being less affected than the two earliest thinnings.

(*a*) *The yields from the various spacings.*—The yields from the 10 spacing-treatments for each sowing-date are compared in Table 8, where full details of the plants per hole and holes per ridge are also given.

TABLE 8. *Yields of Spacings at two Sowing-dates*

(kantars per feddan)

Number of Plants per metre ridge	1	2		4			6	8		16
Number of holes per metre ridge	1	2	1	4	2	1	2	4	2	4
Number of plants per hole	1	1	2	1	2	4	3	2	4	4
Yields										
August-sown	1·62	2·48	2·20	2·78	2·96	2·81	3·18	3·05	3·08	3·15
September-sown	0·94	1·43	1·49	2·36	2·35	2·08	2·88	3·24	3·12	3·70
Yields of August minus yields of September	+0·68	+1·05	+0·71	+0·42	+0·61	+0·73	+0·30	−0·19	−0·04	−0·55
Average of August-sown	1·62	2·34		2·85			3·18	3·07		3·15
Average of September-sown	0·94	1·46		2·26			2·88	3·18		3·70

With both sowing-dates the widest spacings employed gave the lowest yields; but whereas with the August sowing the yield of the widest spacing was 51 per cent. of that of the optimum spacing, with the September sowing the yield was only 25 per cent. of the optimum. Further, with progressively more plants per metre ridge, the August sowings showed little increase in yield with more than 6 plants per ridge: whereas with September sowing the yields increased uniformly with closer spacing, so that the closest spacing employed gave the maximum yield; and there were indications that the optimum number of plants per metre ridge was considerably greater than the highest number per ridge included in the experiment.

This remarkable contrast between August and September sowings fully confirms the results both of the four-factor experiments and of the series of experiments already described in the present paper, within the restricted limits determined by the range of spacings employed. It is also apparent that had the numbers of plants per hole in these experiments been increased above the normal two plants, the response to closer spacing with September sowings would have been still more marked.

Some light is thrown on the mechanism involved in the spacing and sowing-date interactions by considering the results of the yields corresponding to the various dates of thinning in relation to spacing and sowing-date.

The following are the yields for the three dates of thinning for comparisons of number of plants per hole for a spacing of 50 cm. between holes, for each sowing-date:

TABLE 9. *Yields given by Different Dates of Thinning with Different Numbers of Plants per hole*

(kantars per feddan)

	Sown Aug. 12				*Sown Sept. 2*			
Plants per hole	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
Thinned at 3 weeks	2·90	3·13	3·49	3·24	1·45	2·42	2·92	3·07
Thinned at 6 weeks	2·59	3·07	3·21	2·96	1·41	2·19	2·97	3·07
Thinned at 9 weeks	1·93	2·69	2·83	3·03	1·43	2·42	2·75	3·21

The above figures show that, with August sowing, the best yields are obtained with early thinning, and the differences are particularly marked when thinning is drastic, i.e. to one plant per hole. The date of thinning was of little importance in late sowing as compared with early sowing, and these results provide the interpretation of the spacing and sowing-date interaction. It is obvious that the late-sown plants, owing to greater individual plant-development, are unable to compensate to any marked degree for the fewer plants existing with wider spacing, or to respond to early thinning. Consequently it is of less importance when these plants are thinned, the yield being primarily determined only by the *number of plants remaining* after thinning.

With August sowings the plants are able to compensate extensively for any decrease in the number of plants. The number of plants per unit area is therefore not of great importance in determining final yield with such sowings, if thinning to the final stand is early enough to enable the plants remaining to have sufficient time for the additional compensating growth to be produced. This is clearly brought out from the yield figures given earlier; with early thinning the yield with one plant per hole is 90 per cent. of the yield with four plants per hole, whereas with late thinning, and therefore a reduced growing-period after thinning, the single plants produce a yield which is only 64 per cent. of that with four plants per hole.

In the four-factor experiments the main thinning was at four weeks after sowing and in the series of out-station experiments at three weeks after sowing. Hence, in all these experiments, the thinning was sufficiently early to allow of compensation by the wider spacings. The tendency was for August-sown plants to show small differences in yields between spacings. On the other hand the September sowings, where compensation was very slight, produced large differences between spacings, the greater number of plants per unit area with the closer spacing producing the greater yield. Thus an interaction is produced between 'spacing' and 'sowing-date'.

It should be noted that Blackarm was negligible in this experiment; if it had not been, some of the results might have been modified owing to differential sowing-date and spacing-effects [2].

AN ADDITIONAL EXPERIMENT ON SPACING, THINNING, AND SOWING-DATE. HAG ABDULLAH, 1933–4

The interrelation of spacing and thinning with the date of sowing has been further studied in another experiment on a smaller scale at Hag Abdullah carried out in 1933–4, which gave the following yields (kantars per feddan):

Three-factor Experiment on Spacing, Thinning, and Sowing-date

		Sown Aug. 6	*Sown Sept. 6*
A	Spacing 30 cm., no thinning	4·35	4·36
B	,, 30 cm., 4 plants per hole . . .	4·54	3·66
C	,, 60 cm., 2 ,, ,, ,, . . .	2·89	1·61
D	,, 60 cm., 1 plant ,, ,, . . .	3·01	1·07

(Sowings were planted on ridges at 80 cm. apart.)

From 3 replicates per treatment, each plot = 1/22nd feddan

z value for significance of *thinning* = 1·85 (5% = 0·63).

z value for significance of *sown* versus *thinning* = 0·76 (5% = 0·63).

The statistical analysis gave highly significant results for 'thinning', and a significant interaction of sowing and thinning. The results agree with those of a comparable character in the main spacing-experiment described above and extend the range of this experiment in an important respect. The 'no-thinning' treatment of the September sowing not only gave yields almost equal to the maximum for the August sowing, but also showed a highly significant superiority in yield over the four plants per hole, 30 cm. spacing treatment, which was the densest spacing tested in the main experiment.

From these results it is concluded that with late sowings higher yields than are usually obtained could be realized by less drastic thinning than has previously been tested and, in fact, that no thinning at all might give the maximum yield.

REFERENCES

1. F. G. Gregory, F. Crowther, and A. R. Lambert, The Interrelation of Factors controlling the Production of Cotton under Irrigation in the Sudan. J. Agric. Sci., 1932, **22**, 617–38.
2. A. R. Lambert, Plant Observation Section, Gezira Agric. Res. Ser., Ann. Rep., 1933, p. 58.

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